# Science Focus 科言

Issue 017, 2020

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## Message from the Editor-in-Chief 主編的話

Dear Readers,

Since the last issue of *Science Focus*, we have all tried to adapt to a new mode of life. Online learning has become a norm for both secondary schools and universities. Although we are used to learning "life hacks" from social media and online platforms, it is perhaps too soon to assess the outcome of substituting formal lessons with ones delivered via electronic devices. Have you been exploring scientific topics that were not covered in the formal curriculum, during this period of more "flexible" learning? If not, we hope the articles in this issue will provide useful starting points.

Many of the articles are related to food. Did you know that a laboratory accident led to the discovery of artificial sweeteners? For those of you who enjoy a ham sandwich, have you thought about the mathematics of cutting one? What if the ham you used was originally from a laboratory instead of a pig? Furthermore, did you know you have been "sharing" the sandwich with trillions of bacteria in your gut? We also cover topics you may have seen in sci-fi movies such as Star Trek and Terminator. It turns out scientists have been busy making teleportation and shape-changing metal a reality.

To conclude, I wish you all good health and good fortune for the rest of the school year. Stay curious!

Yours faithfully,
Prof. Ho Yi Mak
*Editor-in-Chief*

親愛的讀者：

自上期《科言》出版以後，我們都嘗試著適應我們的「新生活」— 網上學習已經變成了中學和大學日常的教學模式。雖然我們都習慣在社交媒體和網上平台學習一些生活小知識，可是要談及網上課程能否取代正規課堂的話，此刻也許還言之尚早。在這段可以較自由地選擇自己學習方式的期間，您有沒有探索一些課程以外的科學題材？沒有的話，我們希望今期的文章可以為您提供一些學習的契機。

今期不少文章都與食物有關。您知道代糖是怎樣意外地被科學家發現的？喜歡吃火腿三文治的您，有想過切三文治所涉及的數學嗎？那麼如果我告訴您那塊火腿是來自實驗室的，而不是來自豬呢？還有，您知道您其實是與數以萬億計的細菌分享您那塊三文治嗎？今期《科言》還會提及一些您可能在《星空奇遇記》、《未來戰士》等科幻電影看過的情節，然後您會發現原來科學家一直都致力把瞬間轉移和變形金屬化為現實。

最後，希望大家能保持身體健康，並在學期餘下的時間一切順利。還要時刻保持您的好奇心啊！

*主編* 麥晧怡教授
敬上





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# WHAT'S HAPPENING IN HONG KONG ?
# 香港科技活動

## Let Your Love for Science Flourish! 盡情展現你對科學的喜愛！

Are you bored of staying at home? You can have some fun in the two upcoming astronomical events! Stay safe and healthy.

你對足不出戶的日子厭倦了嗎？我們挑選了今年兩個矚目的天文現象讓你觀賞，安全和健康第一！

### SOLAR ECLIPSE — JUNE 21, 2020

On June 21, 2020 (Sun), we will be able to see a partial solar eclipse in Hong Kong, during which about 86% of the Sun will be shaded by the Moon at the greatest eclipse. The annular solar eclipse path will span over the two cities, Xiamen, China and Chiayi, Taiwan, where an annular eclipse can be observed instead.

| Observation from Hong Kong | |
|---|---|
| Start of eclipse | 14:36:59 |
| Greatest eclipse | 16:08:19 |
| End of eclipse | 17:24:26 |

Please observe the solar eclipse safely. There are some tips from the Hong Kong Space Museum. To observe the solar eclipse, you can also make your own paper "pinhole projector" with the PDF file downloaded from their website!

Website: *https://hk.space.museum/en_US/web/spm/exhibition/specialexhibition/2020-astronomical-events.html*

### 日食 — 2020 年 6 月 21 日

在今年 6 月 21 日（日），我們將能在香港觀測到一次日偏食，食甚時月球將掩蓋太陽約 86% 的面積。環食帶將跨越中國廈門和台灣嘉義，屆時以上兩個地區將能觀測到日環食。

| 從香港觀測 | |
|---|---|
| 初虧（日食開始） | 14:36:59 |
| 食甚 | 16:08:19 |
| 復圓（日食結束） | 17:24:26 |

記得使用正確的方法觀賞日食！你可以參考香港太空館提供的小貼士，亦可以用列印太空館網頁上的紙樣來自製一個「針孔太陽投影盒」觀賞日食。

網　址：*https://hk.space.museum/zh_TW/web/spm/exhibition/specialexhibition/2020-astronomical-events.html*

### PERSEID METEOR SHOWER — AUGUST 12, 2020

"I saw a shooting star...and thought of you" — this year, the Perseids is expected to peak on August 12 (Wed), 21:00–24:00. You may observe the meteor shower during the entire night of August 12, and there could be up to 110 meteors per hour (subject to light pollution level, weather conditions, etc.). The moon phase will be 41.9% so the moonlight won't affect our observation much.

Places with wide view of the sky and low light pollution are suitable for the observation, such as the East Dam of the High Island Reservoir, Tai Tau Chau in Shek O, and Tai Au Mun (near HKUST). Please observe the "stargazing etiquette" — use a red light torch and don't shine a torch into others.

To take photos of the starry sky, don't forget to bring a tripod and a wide-angle lens. The summer Milky Way will never disappoint you, too. Get ready for a ton of "likes" from your friends!

### 英仙座流星雨 — 2020 年 8 月 12 日

「陪你去看流星雨落在這地球上」— 今年英仙座流星雨的高峰期預計是 8 月 12 日（三）晚上 21 時至 24 時。你可以在 12 日的整個晚上觀賞，預計每小時最多會有約 110 顆流星在夜空劃過（亦受光害、天氣等因素影響）；當晚月齡為 23（農曆廿三），觀測尚算不太受月光影響。

天空視野廣闊和光害較少的地方都適宜觀測是次流星雨，本港的觀星熱點有萬宜水庫東壩、石澳大頭洲以及離科大不遠的大坳門等。觀星時記得遵守「觀星禮儀」，包括使用紅光手電筒，及不要把光照向別人。

想嘗試天文攝影的朋友記得攜帶三腳架和廣角鏡頭。夏季銀河也絕對不會令人失望的，各位文青們又可以準備好「呃 like」了！

*The Sweetest Encounter:*

# DISCOVERY OF THE FIRST ARTIFICIAL SWEETENER

# 最甜的巧遇——首隻人工甜味劑

**By Yasine Malki 馬建生**

Artificial sweeteners are commonly found in many "diet" varieties of food and drinks: from soft drinks to bakery goods, canned fruits and syrups. These sweeteners are synthetic substitutes of sugar, with little to no caloric content. You might see the common ones, like sucralose or aspartame among the ingredients of your favourite snack or drink! But did you know that the discovery of the first artificial sweetener, saccharin, came from experiments with coal tar and an accidental laboratory spillage?

Ira Remsen was a passionate German chemist who flourished in his work on sulfobenzoic compounds[1] [1] at Johns Hopkins University. Around 1877, a Russian chemist, Constantin Fahlberg, had joined his lab and they were working together to oxidize a coal-tar sulfobenzoic derivative [2], *o*-toluenesulfonamide [3].

One day when Fahlberg went home for dinner and took a bite at a piece of bread, he was shocked to find it tasted incredibly sweet! He also detected that both his hands and arms also tasted sweet, even though he had washed them thoroughly! He concluded that the sweetness came from insoluble remnants of an earlier chemical spillage over his hands. Being desperate for answers, he returned to the lab and tasted all the glassware on his bench until he found the substance with "eminent sweetening power." [4] This turned out to come from an overboiled mixture of *o*-toluenesulfonic acid, phosphorus pentachloride and ammonia, which resulted in *o*-benzosulfimide. Remsen and Fahlberg published their discovery in 1879, describing the compound as "even sweeter than cane sugar." [1]

However, this is where the sweet story took a bitter turn. After Fahlberg left Remsen's lab, he started to realize the commercial potential of *o*-benzosulfimide and further optimize its synthesis for large-scale production, even conducting safety tests by feeding the compound to animals and himself [4]. He realized that the compound was not metabolized by the body and was eliminated in the urine unchanged — meaning that it could probably be a replacement of sugar for diabetics and dieters, because it did not alter blood sugar levels nor provide any calories. Fahlberg filed patents[2] for this substance in several countries under the name "saccharin" without Remsen's knowledge or permission, and even claimed to be its sole discoverer. These actions left Remsen feeling betrayed and furious.

Saccharin quickly gained popularity in the US nevertheless, becoming a nation-wide success and a booming industry. Its increased consumption soon drawn the attention of health experts. After studies revealed a link between saccharin consumption to the development of bladder cancer in male rats [5], its use became highly scrutinized. For around 19 years, saccharin had to be sold with a warning label [1] until further research showed that those male rats had had unique physiological conditions (high levels of urinary proteins and calcium phosphate) that triggered their tumor formation by producing microcrystals with


saccharin [6, 7], and these conditions do not apply to humans at all [8].

You may be wondering how can a molecule like saccharin, that is not sugar, tastes sweet? This is actually a result of its specific molecular shape, allowing it to trigger sweet taste receptors on the tongue through a lock-and-key mechanism. These receptors transmit electrical impulses to the brain, creating the perception of sweetness. The structural requirement for molecules that act as "keys" to the sweet taste receptor "lock" is described as a "triangle of sweetness" [9]: it needs to contain two sites for forming hydrogen bonds[3] with the receptor — one with an O–H or N–H group and one with an O or N atom — and a third site of a water-repelling group (e.g. hydrocarbon), forming a triangular geometry within specific dimensions (***Figure 1(a)***). This configuration is demonstrated in saccharin (***Figure 1(b)***: an N–H group, one of the oxygen atoms on sulfur and the hydrophobic benzene ring) [10], allowing it to bind perfectly into the sweet taste receptor's cavity. This same phenomenon also occurs for other sweet-tasting substances, such as glucose, sucrose or aspartame.

However, evidence suggests that saccharin also activates other taste receptors on the tongue, including the T2R bitter taste receptor and the vanilloid receptor 1 (TRPV1). These may explain the bitter and metallic aftertaste of saccharin, respectively [11].

This first commercialized artificial sweetener, saccharin "Sweet'N Low™", had inspired the development of similar products with improved tastes, such as aspartame "Equal™" and sucralose (Splenda™). More recently, sugar alcohols (e.g. erythritol and xylitol) and plant extracts (e.g. Stevia and Monk Fruit) are trending as "healthier" natural sugar substitutes. Consumers today should be content that such a wide range of sweetening options are available in the market, offering them the sweetness of sugar without the risks of weight gain or developing diabetes!

**WARNING: NEVER TRY THIS IN YOUR SCHOOL LAB!**

Although it may seem tempting to touch and taste the chemicals and biological samples in your school lab, and you might make great discoveries...most chemicals are not safe to consume or handle. It is always a good practice to wear gloves in the laboratory and to wash your hands thoroughly afterwards. Most importantly, NEVER taste or consume any laboratory chemicals!

人工甜味劑常見於多種低糖食品和飲料，由汽水到烘焙食品、罐頭水果和糖漿。這些甜味劑都是糖的合成替代品，又稱代糖，只含有少量甚至不含卡路里。你可能在你喜愛的零食或飲料的材料中發現常見的三氯蔗糖（sucralose，又名蔗糖素）或阿斯巴甜（aspartame）。可是，你知道第一隻人工甜味劑 — 糖精（saccharin）的發現是來自煤焦油的實驗，而且涉及一次實驗品溢出意外嗎？

Ira Remsen 是一位充滿熱誠的德國化學家，他在約翰霍普金斯大學（Johns Hopkins University）研究磺基苯化合物[1]（sulfobenzoic compounds）[1]，而且頗有成就。在 1877 年左右，俄羅斯化學家 Constantin Fahlberg 加入他的實驗室，兩人著手嘗試氧化煤焦油衍生物 [2] — 鄰甲苯磺酰胺（*o*-toluenesulfonamide）[3]。

一個晚上，Fahlberg 在回家用膳的時候，吃了一口麵包。然後，他驚訝地發現那麵包吃起來竟然難以置信地甜。他還意識到自己的雙手和手臂嚐起來都是甜的，即使之前已經徹底洗手。他猜想那甜味應該來自之前的實驗事故 — 溢出的化學物質應該在他的雙手留下了不可溶的殘留物。由於非常渴望找出答案，他回到了實驗室，並把實驗桌上的所有玻璃容器都嚐了一次，直至他找到那「帶有強烈甜味」的物質 [4]。結果，那物質來自因煮沸而溢出、由鄰甲苯磺酸（*o*-toluenesulfonic acid）、五氯化磷（phosphorus pentachloride）和氨（ammonia）合成出的鄰磺酰苯甲酰亞胺（*o*-benzosulfimide）。Remsen 和 Fahlberg 在 1879 年發表這個發現，並以「比蔗糖還要甜」來形容這化合物 [1]。

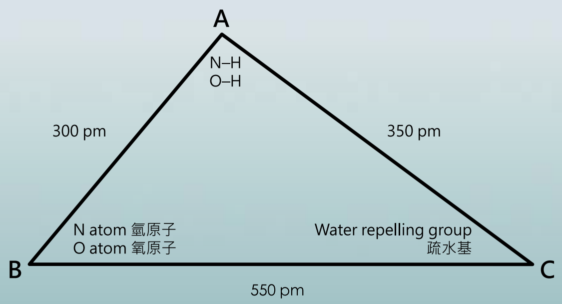


***Figure 1(a).*** *The "triangle of sweetness" showing the structural requirements to activate the sweet taste receptors on the tongue [9]. The numbers shown are the ideal distances between the three sites (picometer (pm): $10^{-12}$ meter).*
***圖一甲*** *啟動甜味感受器所需的分子結構 —「甜味三角」 [9]。圖中的數字表示三個位置之間的理想距離（皮米 (pm): $10^{-12}$ 米）。*

然而，這個甜滋滋的故事卻有一個苦澀的轉折。Fahlberg 離開 Remsen 的實驗室後，開始意識到鄰苯甲酰磺酰亞胺的潛在商機。他更進一步改良其合成過程以便作大規模生產，甚至還在動物和自己身上進行安全測試 [4]。他發現該化合物不會在體內被代謝分解，而會直接隨尿液排出體外 — 意味著它可以作為糖的替代品，供糖尿病患者和節食人士使用，因為它既不會改變血糖水平，又不會提供任何熱量。在 Remsen 不知情和沒有授權的情況下，Fahlberg 以「saccharin（糖精）」的名稱在數個國家申請了專利[2]，並聲稱自己唯一的發現者，使 Remsen 感到受背叛和憤怒。

儘管如此，糖精很快就在美國變得街知巷聞，成為一個舉國皆知的成功故事和新興產業。其日益增加的消耗量卻很快引來了健康專家的注意。在多個雄性大鼠的研究中發現食用糖精與膀胱癌有關之後 [5]，糖精的安全性被仔細審視。在其後的大約十九年間，糖精在售賣時被勒令加上警告標示 [1]，直至進一步研究指出雄性大鼠有著獨特的生理特徵，例如高尿蛋白和磷酸鈣水平，使糖精參與微晶體的形成，而導致腫瘤的形成 [6, 7]，然而這些狀況並不會發生在人類體內 [8]。

你可能會想：為何一個不是糖的分子（例如糖精）會有甜味？這其實是因為其特有的分子結構，使其可以像鑰匙解鎖一樣，啟動舌頭上的甜味感受器所致的。這些感受器會向大腦發出電脈衝，令我們感覺到甜味。這個像「鑰匙」一樣的分子結構要求被形容為「甜味三角」，用以對應我們的「鎖」 — 甜味感受器。「甜味三角」需要有兩個與感受器產生氫鍵[3]的位置：一個位置包含 O–H 或 N–H 基、另一個包含氧或氮原子；第三個位置則需要為一個疏水基（例如碳氫化合物），三者形成一個特定大小的三角形的結構（***圖一甲***）[9]。糖精亦呈現這個結構（***圖一乙***：它有一個 N–H 基、與硫原子連結的氧原子和一個疏水的苯環）[10]，使其可以完美地與甜味感受器的凹洞結合。這

現象亦出現於其他帶有甜味的物質，例如葡萄糖、蔗糖和阿斯巴甜。

然而，有研究亦指出糖精可以啟動舌頭上其他的感受器，包括 T2R 苦味感受器和香草第一類受器（TRPV1）。這分別是糖精帶有苦味和金屬味餘韻的可能原因 [11]。

作為第一隻推出市場的人工代糖，糖精（Sweet' N Low™）啟發了同類產品的發展，像是阿巴斯甜（Equal™）和三氯蔗糖（Splenda™），這些產品在味道上都經過改良。近年亦流行著糖醇（赤藻糖醇、木糖醇等）和植物提取物（甜菊糖、羅漢果糖等）這些被標榜為較健康的天然代糖。消費者應該為今時今日市面上琳瑯滿目的代糖選擇感到滿足，因為這能使我們嚐到甜味的同時，免受體重增加和患上糖尿病的風險。

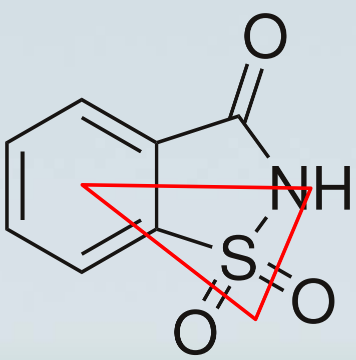


***Figure 1(b).*** *The "triangle of sweetness" in saccharin [10]. The electron-rich region between the two oxygen atoms can form a hydrogen bond with the sweet taste receptor.*
***圖一乙*** *糖精的「甜味三角」[10]。兩個氧原子中間電子密度高的位置可以與甜味感受器形成氫鍵。*

**警告：不要在你的學校實驗室裡嘗試！**

雖然觸摸和輕嚐實驗室裡各種化學品和生物樣本的想法可能十分誘人，而你可能因此取得重大發現……可是大多數的化學物質都不宜進食或用手直接接觸。在實驗室內，我們應該戴上手套，並在實驗後把雙手徹底洗淨。最重要的是：不要吃下任何實驗用的化學品！

[1] Sulfobenzoic compounds: Compounds containing a sulfoxide group attached to a benzene ring ($Ph–SO_2R$)
磺基苯化合物：一個類別的化合物，包含一個帶有苯環的亞碸（$Ph–SO_2R$）

[2] Patent: A right or ownership to protect a certain invention by preventing others from making, using and selling it, which usually lasts 20 years from the filing date.
專利：對一個發明的擁有權，可以透過防止別人製造、使用和售賣，從而保護相關發明。有效期通常為由申請日起計的二十年。

[3] Hydrogen bond: A relatively weak, non-covalent intermolecular interaction between an electronegative atom (N, O, F) and the hydrogen atom covalently bonded to another electronegative atom (N, O, F)
氫鍵：一個非共價、相對較弱的分子間吸引力，會出現在一個電負性大的原子（氮、氧、氟）和一個與電負性大的原子（氮、氧、氟）結合的氫原子之間。


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# Quantum Teleportation, Fax a Particle to the

Quantum teleportation is an unfortunate misnomer. Contrary to what portrayals from popular media and news titles might suggest (like "*First teleportation from Earth to orbit*" [1]), quantum teleportation is closer to a facsimile machine than a transporter. It's like copying data across two computers, except that here we are transmitting the data of particles instead. More precisely, it produces a particle at site B identical to a particle at another site A without ever physically transporting the particle.

At first glance, this might appear straightforward. All electrons are essentially identical, and identical particles are indistinguishable, although they may be in different quantum states. If we want to teleport an electron at site A to site B, we only need to get all parameters that characterize electron A — like its position, momentum and spin — and manipulate electron B so it has the same parameters. This approach is, however, prohibited by Heisenberg's uncertainty principle, which states that one can

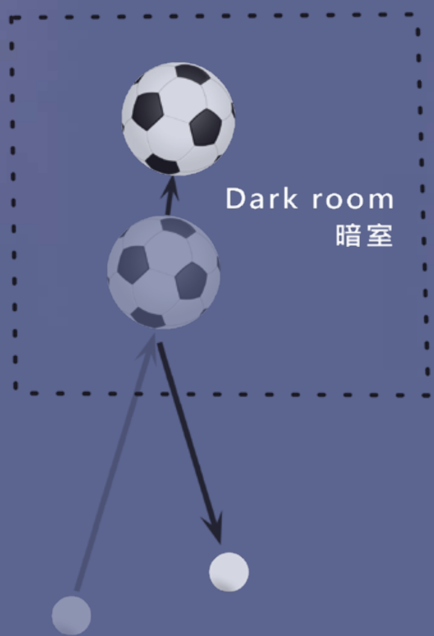


***Figure 1. 圖一***

量子遙傳(quantum teleportation)的取名其實不太恰當；與大眾媒體或新聞標題給人們的印象相反(諸如〈首顆粒子從地球傳送到太空軌道〉(*First teleportation from Earth to orbit*) [1] 等)，量子遙傳與其說是傳輸，其實更加像傳真。其道理跟在兩台電腦之間傳送資料十分類似，不過現在我們只是傳送粒子的資料而已。更準確地說，過程中會在 B 點產生一顆與 A 點粒子相同的粒子，而從不需要移動 A 點的粒子。

這乍眼一看不算複雜。所有電子本質上皆完全一樣，不可區分，雖然它們的量子態可能不同。如果我們想把一顆電子從 A 點傳送到 B 點，我們只需要取得所有描述電子 A 的參數 — 譬如說，其位置、動量和自旋 — 然後改造電子 B，使它的所有參數都與電子 A 相同。遺憾地，這個方法違反海森堡不確定性原理(Heisenberg' s uncertainty principle)；這原理指出我們永遠都不能得知一顆粒子的所有物理特性[1]。所有測量都無可避免地改變物體。譬如說，我們要照亮一個物體，才可以看到它而知道其位置。光由很微小、名為光子[2] 的粒子組成。儘管一顆光子的大小不足以影響宏觀的物體，當我們開始考慮微觀尺度時，光子所施的力就會變得越來越顯著。因此，當我們用光子測量

[1] For readers who learned some quantum mechanics before, the uncertainty principle is a direct result of the phenomenon of "wavefunction collapse." A wavefunction collapses whenever it is observed, so information is lost. Interested readers can refer to the article "*Quantum Mechanics — Your Eyes Can Kill Schrödinger's Cat*" from Issue 016 for an excellent introduction.
如果讀者有接觸過量子力學的話，不確定性原理其實就是「波函數坍縮」(wavefunction collapse)的結果。波函數會在觀察之下坍縮，所以部分資訊會在過程中損失。感興趣的讀者可以參考第十六期的〈量子力學 — 你的雙眼能殺死薛丁格的貓〉，它是一個精彩的引入。

[2] You might have learned that light is a wave because it produces interference patterns, but light is also a particle. This is a result of wave-particle duality, and again, interested readers can refer to the article in the above footnote.
你可能學過光是波的一種，因為它會產生干涉現象。但光也是一種粒子，這是波粒二象性(wave-particle duality)的結果。同樣地，感興趣的讀者也可以參考以上註腳中的文章。

never determine all physical properties of a particle[1]. Measurement inevitably alters an object. For example, to see an object and know its position, we need to shine light onto it. Light is composed of tiny particles called photons[2], and while a photon is too small to influence a macroscopic object, as we reduce the object's scale to atomic level, the force of a photon becomes significant. Therefore, once we determined the position using the photon, it would have kicked the particle away. ***Figure 1*** is an analogy in our macroscopic world: if we are only allowed to find out the position of a football in a dark room by shooting billiard balls, we can imagine that, even if we knew where the football was from the trajectory of the billiard ball, the football would have already been struck to a new position. This, then, seems to rule out any hope of remotely transmitting a particle's data.

Fortunately, we do not need to explicitly know everything about a particle in order to transmit its state. The key is a property known as entanglement. The characteristics of a pair of entangled particles, A and B, can be described as a single system, such that the state of each member can be measured and used to infer that of the other. Moreover, the change induced in A is also mirrored in its empathetic twin B even though the two particles are separated far apart — that's why Einstein called this "spooky action in a distance." Imagine a pair of mischievous, telepathic twins who hate giving the same answer to the same question — if one answers yes, the other will answer no — and this is how a pair of entangled particles behave.  Measurements can be made to gather information on the system, but they inevitably introduce further changes to the system.

Entanglement is the main principle behind the quantum teleportation achieved by a group of six researchers at IBM in 1993 [2]. Here's an abridged version of their procedure: Suppose, as ***Figure 2*** shows, Alice and Bob each gets one particle from the entangled pair A-B. Alice, who wants to transmit

# or How to Orbit

# 量子遙傳 — 粒子傳真大法

By Terrence Tai 戴煒庭

到一顆粒子的位置後，這顆粒子已經被光子彈走了。***圖一***是一個在宏觀世界的比喻：如果我們只能以桌球撞擊足球的方式在暗室中找出足球的位置，我們可以想像，就算我們從桌球的軌跡計算到足球原本的位置，足球已經被撞到一個新的位置了。這樣看起來，遙距傳送粒子資訊的方法似乎變得沒有可能。

幸好的是，我們可以在不需要知道粒子的所有資訊下傳送它的量子態，其關鍵在於名為量子糾纏(quantum entanglement)的特性。相互糾纏的粒子 A 和 B 的特性可以被描述成一整個系統，我們可以只量度其中一顆粒子的特性，從而推斷出另外一顆的特性。除此之外，更加奇怪的是粒子 A 和 B 可以相隔萬里，但我們對粒子 A 的施加的改變仍然會共鳴到粒子 B — 這就是愛因斯坦把其稱為「詭異的超距作用(spooky action at a distance)」的原因。想像一對有心靈感應能力、喜歡鬥嘴的雙胞胎，他們從不會就同一條問題給相同的答案 — 如果一個說是，另一個就會說不 — 這正是相互糾纏粒子的行為模式。我們可以對其進行測量，蒐集這個系統的資訊，不過所有測量都無可避免地會引起更多的改變。

IBM 的六個研究者在 1993 年設計的量子遙傳方法[2]，就是運用了量子糾纏作為基本原理。以下是其簡略版的過程：如***圖二***所示，一開始 Alice 和 Bob 從一對相互糾纏的粒子 A-B 中分別獲得了一顆粒子。 Alice 想把另一顆

another particle, C, to Bob, entangles her particle A with C, so B is also remotely influenced by the combined A-C system even though they have been separated. Then, Alice performs a standard measurement on A-C and sends the result to Bob. Although the data alone is insufficient to describe C, Bob can make use of the data to transform B, which is remotely influenced by the measurement, so that it becomes identical to the original C. Meanwhile, the original C and its entangled twin A are both destroyed by the measurement. This is how Alice and Bob can "teleport" a particle without knowing everything about its state.

Quantum teleportation has become a staple in quantum technology since experimentalists successfully teleported photons as a proof of concept in 1998 [3]. One potential application is in secure quantum communication [4]: the uncertainty principle prevents hackers from eavesdropping quantum communication without alerting the recipient, because any measurement on the transmission alters the message. Recent experiments have demonstrated that qutrits, a three-state system, can be teleported, which is yet another step to realize large-scale quantum internet [5]. On an even grander scale, will we be able to teleport humans? Sci-fi fans will be disappointed to learn that most mainstream scientists deem the technological hurdles insurmountable in the foreseeable future.

粒子C傳送給 Bob，所以她把她的粒子 A 和 C 糾纏在一起，讓在遠處的 B 也會受到 A-C 系統影響。然後，Alice 對 A-C 系統進行一次測量，把結果傳送給 Bob。雖然數據本身不足以描述 C，但 Bob 可以根據這些資料變換（transform）受到遙距影響的 B，使其變成與原來 C 相同的量子態；而原來的 C 和與它相互糾纏的「孿生兒」A 則在測量中受到破壞。這就是 Alice 和 Bob 如何在不知道一顆粒子的量子態的情況下能夠「遙傳」它的方法。

自從在 1998 年一隊實驗人員成功示範量子遙傳 [3] 之後，它就成為了量子技術的重要一環。它其中一個可能的應用是在安全量子通信方面 [4]：不確定性原理防止黑客在接收者不知情的情況下竊聽量子通信，因為傳輸過程中的任何測量都必定會改變訊息。最近實驗成功遙傳量子三元（qutrit），一個有三個狀態的系統（three-state system），而這是實現大規模量子互聯網的另一大步 [5]。在更大的規模上，我們能夠傳送人類嗎？科幻故事迷可能會感到失望，因為大多數主流科學家都認為，我們無法在可預見的將來克服當中的技術困難。

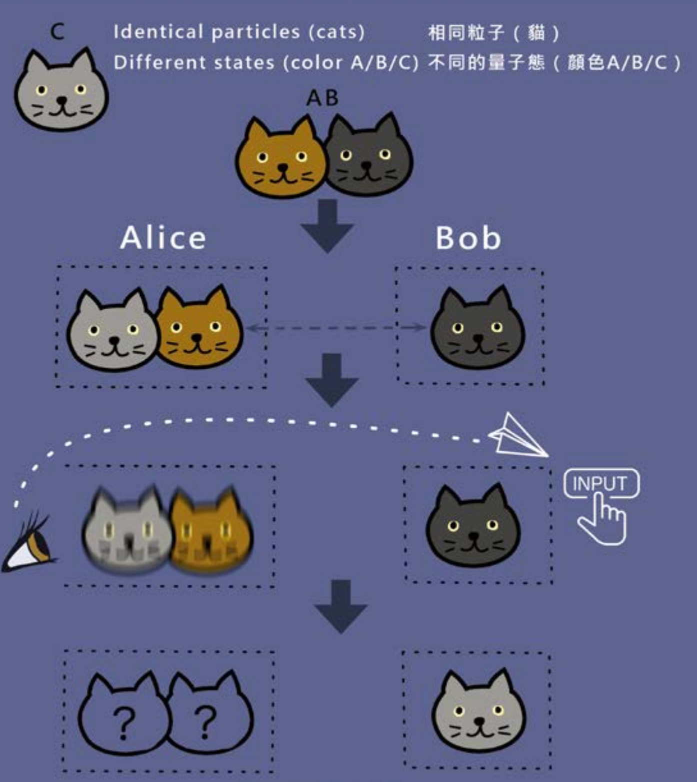


*Figure 2.* 圖二

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### PROGRAMMABLE LIQUID MATTER:

# A METAL THAT "BENDS" TO YOUR WILL

### 可編程液態物質：

# 能被隨心所欲地操縱的變形金屬

**By Henry Lau 劉以軒**

To your knowledge, how many elemental metals are liquid at room temperature? The answer, of course, is one: mercury as it possesses a melting point of –38.8°C. Besides mercury, scientists have been busy at work to create alloys, by the fusion of two or more metals, which would also assume the liquid state at room temperature. What may astound you more is that in recent years, scientists have also created liquid metals that can assume predetermined shapes on command. This exciting avenue of research, albeit in its infancy, has been dubbed by many as "programmable liquid matter."

The basic idea that led to the rise of programmable liquid matter is a concept first suggested in 1991: "programmable matter." [1] From the name itself, you can already infer that the material is meant to be able to change its physical properties based on the user's instructions. The change is triggered by an input of some sort, be it environmental or user-induced. Hence, the term "programmable" is used as it is similar to giving the matter a "program" to run on when changing its physical properties. In the context of programmable liquid matter, it means that the liquid metal in question will be morphed into various fixed shapes. Sometimes, even its physical properties such as electrical conductivity and surface tensions can be modified. A particular research team from the Universities of Sussex and Swansea created an alloy that can morph from one shape to another according to the direction of an electric field [2].

Before actually making the liquid metal move, researchers had to do a lot of work. To start with, they created a low melting point eutectic[1] alloy composed of gallium (Ga) and indium (In), which looked like mercury in its appearance. In order to allow the liquid metal to twist and move to assume different shapes, it was pre-treated with sodium hydroxide (NaOH), a highly alkaline solution. The hydroxide ions served to generate negative charges on the liquid metal surface by reacting with gallium to form some tetrahydroxogallate(III) anions ($Ga(OH)_4^-$). Meanwhile, $Na^+$ cations in the solution would be electrostatically attracted to the negatively charged blob, coating it with a uniform positive charge (***Figure 1***). Under this equilibrium state, the blob would assume its most stable shape — a perfectly symmetrical sphere.

This charged form of the liquid metal can be deformed when charges are applied to it via electrodes. When the anode (positive terminal) comes into contact with the liquid metal sphere, the surface charge of the blob would switch from negative to positive. This disrupts the previously established charge equilibrium, causing the spherical blob to collapse, flatten, and gradually spread towards the cathode (negative terminal) (***Figure 2***). As a result, we could make the liquid metal move in any desired direction by controlling the position and voltage of the electrodes. To enable an all-rounded control of the liquid metal's movement, researchers suspended it on a 7 x 7 electrode array. By programming a sequential change of the voltage and connectivity for the 49 individual electrodes in the array, they have managed to control the liquid metal's form to take the shape of the letter "S" or that of a "heart." (***Figure 3(a) & 3(b)***)

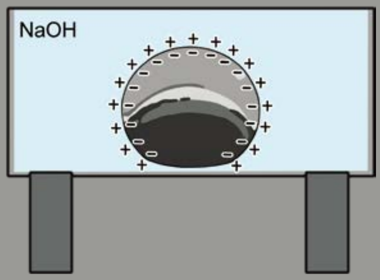


*Figure 1.* ***圖一*** [2]

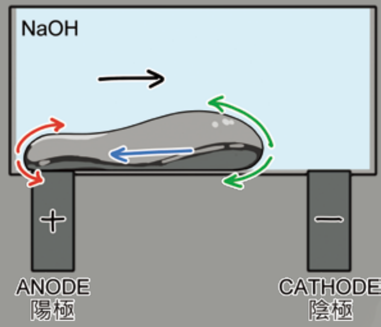


*Figure 2.* ***圖二*** [2]

There are undoubtedly many quirky applications, bordering on sci-fi, for this programmable liquid matter in the fields of robotics, medicine and military. In terms of robotics, it may be possible to manufacture more flexible robotic components, which will allow for greater reach and the ability to squeeze through tight spaces that conventional robotics are incapable of achieving [3]. Likewise, programmable liquid matters may have useful applications as a nano-drug carrier or as a minimally invasive surgery tool. On the military side, it's possible that programmable liquid matter can create self-repairing metal armor for military vehicles to increase their durability.

However, there are still many limitations to the current form of this technology. One major obstacle lies in the pre-treatment phase to create the programmable liquid matter in question as it requires large amounts of alkaline electrolytes, a highly corrosive substance, for even a tiny droplet of programmable liquid matter. As a result, it is hardly cost-effective in its production. Another limitation is the difficulty to manipulate the liquid metal outside of a lab setting as the technology relies on an electric field and is easily disrupted outside of a controlled environment.

This is the story of programmable liquid matter: a new, previously unimaginable class of materials that can literally bend to your will thanks to electric fields. While the technology is still in its infancy, we'll hopefully see these programmable liquid matters in action for some revolutionary robotic components and in various other applications.

[1] Eutectic system: A mixture of substances, in a specific proportion, that contains a lower melting point when compared with its constituent substances' melting points or any mixtures of different proportions [4]. This allows the gallium-indium alloy to assume a liquid state at room temperature even though its constituent gallium and indium metals are solids at room temperature.

根據你的知識，有多少個金屬元素在室溫是呈液態的？答案當然是一個，就是汞（Hg；俗稱水銀），因為它的熔點只有 –38.8 攝氏度。 除了汞之外，科學家也一直嘗試透過結合兩種或更多種金屬，製造在室溫下呈液態的合金。更奇妙的是，近年科學家製造了一些可以按指令變成特定形狀的合金。這個研究範疇被稱為「可編程液態物質（programmable liquid matter）」，雖然這方面的技術還沒完全成熟，但距今發展已經令人興奮不已。

可編程液態物質是從「編程物質（programmable matter）」的概念而來。後者在 1991 年被首次提出 [1]，顧名思義，是指一種可以根據用家指示改變其物理性質的材料。這些改變是由一些對其「輸入」的指令而引發的，可以是從四周的環境來的，或是從用家而來的。因為改變其物理性質的過程就像讓物質執行一個「電腦程式」，因此被形容為「可編程（programmable）」。作為可編程液態物質，這種液態金屬除了會被操控而變成不同固定的形狀，有時甚至可以改造其他物理性質，例如導電率和表面張力。一組來自薩塞克斯大學（University of Sussex）和史雲斯大學（Swansea University）的科學家就研發了一種可以隨著電場方向變形的合金 [2]。

在讓合金變形之前，研究人員需要進行很多準備工作。首先，他們製造了一種由鎵（Ga）和銦（In）組成、擁有低熔點的共晶[1]合金，它看來就像水銀一樣的。為了讓這種液態金屬能扭動和流動成不同形狀，它要先經過強鹼性氫氧化鈉（NaOH）溶液的處理。氫氧離子（$OH^-$）的作用是令液態金屬表面產生負電荷，因為它會與鎵起化學反應而產生陰性的四羥基合鎵酸根離子（$Ga(OH)_4^-$）。同時，溶液中的鈉離子（$Na^+$）會被帶負極性的合金團吸引，使合金團被均勻的正電荷包圍（***圖一***）。 在達致平衡的狀態下，合金團會呈現其最穩定的形狀 — 完全對稱的球體。

我們可以透過電極提供電荷，使這團帶極性的液態金屬塌下。當陽極（正極）與液態合金球體接觸時，合金表面的極性便會從負極性變成正極性。這會破壞原來的電荷平衡，使合金球體坍塌下來，變成一堆扁平的合金，並逐漸向陰極（負極）伸展 ***（圖二）***。 就是這樣，科學家可以透過控制電極的位置和電壓，使液態金屬流向理想的方向。要全面地控制液態金屬的流動，研究人員把液態合金放在一個 7 x 7 的電極陣列上。通過設定一系列的程序改變 49 個獨立電極的電壓和連接性，他們成功改變液態金屬的形狀，使其變成「S」形和心形 ***（圖三甲*** 及 ***圖三乙）***。

因此，可編程液態物質已不再是科幻情節，在機械人、醫療和軍事層面上，這項科技肯定會有著不少不可思議而有趣的應用機會。在機械人身上，這項技術可能可以應用於生產更靈活的機械零件，能擠過傳統機械人不能通過的狹窄空間，到達更遠的地方 [3]。同樣地，可編程液態物質也許可以被應用於納米藥物載體或微創手術工具上。在軍事層面方面，它或者能夠用於製造供軍用車輛使用的自我修復金屬裝甲，以提高車輛的耐用性。

可是，現時這項技術還有著很多限制。其中一個主要的障礙在於使用鹼性物質處理合金的步驟，因為製造少量的可編程液態物質也需要用上大量的鹼性電解質 —— 一種極具腐蝕性的物質，導致製作程序的性價比並不高。另一個限制在於我們很難在實驗室以外的環境操縱液態金屬，因為這項技術需要依賴電場，而且在受控環境（controlled environment）外很容易受外界干擾。

這就是可編程液態物質的故事：它是一種前所未有的嶄新材料，透過操控電場，你可以隨心所欲地控制它的形狀。雖然這項技術依然在起步階段，但在不久的將來，我們希望可以看到可編程液態物質被應用於機械零件以及不同領域上。

1 共晶系統：一個由不同物質在特定比例下組成的混合物；在這個特定的比例下，混合物的熔點會比其各個構成元素的熔點或在其他比例下混合物的熔點還要低 [4]。這令鎵銦合金在室溫下呈液態，即使鎵和銦在室溫下都呈固態。

***Figure 3(a) and 3(b).*** [2]
***圖三甲及圖三乙***


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# 光學鑷子 OPTICAL TWEEZERS

By Chih-yu Lee 李致宇

When it comes to LASER (aka light amplification by stimulated emission of radiation), what will you think of? Is it the LASER gun in *Star Wars*, or its everyday applications in scanner, optical communication and CD player? Although we may take it for granted, three excellent physicists, Arthur Ashkin from Nokia Bell Labs, Gérard Mourou from École Polytechnique and Donna Strickland from University of Waterloo, were awarded the Nobel Prize in Physics 2018 because of this technology. This article will introduce the optical tweezers invented by Arthur Ashkin.

By the use of a highly focused light source, optical tweezers are a tool that allows optical trapping, and the manipulation of many micro- and nano-scale materials. It harnesses the radiation pressure of light, which generates force to move tiny transparent objects. Through this mechanism, scientists are able to move cells and their constituent molecules around, with micro- or nano-meter precision. Technically, spherical particles whose wavelengths are "out of the range" for optical tweezers can still be captured and manipulated. To do so, scientists need to split the force of optical tweezers into two: the gradient force, which is linearly proportional to the gradient of the light intensity and the dispersion force, which is linearly proportional to the light intensity. Although the latter hinders capture, it is the fundamental force in optical manipulation and LASER cooling. Additional challenges came from objects that are not spherical in shape. Ultimately, the success of optical trapping is dependent on the precise shape and composition of the experimental subject. Despite of these obstacles, not only did the scientists overcome them, but they also applied the technique to nanotechnology, biology, random thermodynamics in physics, spectroscopy, Casimir force, and active matter.

Among all applications that employ optical tweezers, the most crucial one to medical development is its application in spectroscopy. When combined with Raman spectroscopy, which is a technique for the detection of the vibrational and rotational modes of molecules or crystal lattices, it is possible to diagnose whether a cell is healthy or sick. The said combinational technology is called Raman tweezers or laser tweezers Raman spectroscopy (LTRS).

Using Raman tweezers, physicists Aseefhali Bankapur et al. have conducted research on single living red blood cells and white blood cells. They used high-focused near-infrared (1064 nm) LASER to capture a single cell, and used 785-nanometer light beam with a power of several milliwatts as the incident light to achieve Raman excitation. By using such highly sensitive double-wavelength spectrophotometer, the researchers succeeded in obtaining a signature Raman spectrum for red blood cells. Unsurprisingly, some signals in the spectrum were derived from hemoglobin. The same technology was used in the analysis of white blood cells, including granulocyte and lymphocyte. Again, characteristic vibrational spectra were obtained based on their constituting proteins and nucleic acids. What is the significance of this study? The shape and content of blood cells can change when they are damaged or under stress. The ability to detect these changes by Raman tweezers may therefore contribute to the accurate diagnosis of blood cell disorders.

After reading this article, I hope you appreciate that a technology that warrants a Nobel Prize in physics can also have a huge impact on other fields. In this case, optical tweezers gave biologists a precious tool to analyze cells in an unprecedented way. Can you think of any other examples?

當人們提到「鐳射」(light amplification by stimulated emission of radiation/LASER)，第一個從你腦海中浮現的畫面會是什麼呢?是電影《星球大戰》中的武器鐳射槍，抑或是它在掃描機、光學通訊、光碟播放器等生活中的應用呢?這項我們已經在生活中習以為常的技術，卻使得三位傑出的物理學家榮獲 2018 年的諾貝爾物理學獎，分別是:來自美國貝爾實驗室(Nokia Bell Labs)的 Arthur Ashkin、來自法國巴黎綜合理工學院(École Polytechnique)的 Gérard Mourou 以及來自加拿大滑鐵盧大學(University of Waterloo)的 Donna Strickland。其中，本文便要介紹由 Arthur Ashkin 所發明的「光學鑷子」(又稱光鉗)。

光學鑷子是一個藉由高度聚焦光源來進行光學捕捉(optical trapping)，操縱眾多微米及奈米級材料的工具。它利用光的輻射壓力，進而產生力來移動微小的透明物體。藉由這樣的操作，科學家得以移動微米、奈米等級的細胞及其構成分子。技術層面來說，在操作一些超過光學鑷子可捕捉的波長範圍外的球形粒子時，科學家們會將光學鉗子的力一分為二，分別為與光強度梯度成正比的梯度力和正比於光強度的分散力。雖然後者對於捕捉是有害的，但它卻是光學操作及鐳射冷卻最基本的力。另一個挑戰在於物體的形狀不是球形的情況，而最終光學捕捉是否成功取決於物體的形狀和成分。雖然有著這些障礙，科學家們不但一一克服了，更將其應用於納米科技、生物學、物理上的隨機熱動力學、光譜學、卡西米爾力(Casimir force)以及活潑物質(active matter)。

在這麼多的應用中，對於醫藥發展最重要的是光學鑷子在光譜學上的應用。光學鑷子與拉曼光譜學(Raman spectroscopy)的結合運用是可以用來辨別一個細胞是健康抑或是病變的;而拉曼光譜學本身一種用以研究分子和晶格的振動、旋轉模式的一種分光技術。科學家們稱這種結合的技術為拉曼鑷子(Raman tweezers)或是鐳射鑷子拉曼光譜學(laser tweezers Raman spectroscopy/LTRS)。

物理學家 Aseefhali Bankapur 等人藉由拉曼鑷子研究單個的活紅血球與白血球。他們利用高度聚焦且近紅外線波長(1064 奈米)的鐳射來捕捉單一細胞，並使用 785 奈米的光束來達成約幾個毫瓦的入射光功率以達成拉曼激發(Raman excitation)。透過使用高敏感度的雙波長分光光度計(double-wavelength spectrophotometer)，研究人員成功紀錄紅血球獨有的拉曼光譜;而合理地，光譜中的一些訊號來自血紅蛋白。同一項技術亦被用於分析白血球，包括顆粒球和淋巴球。同樣地，研究人員亦取得了它們特有的振動光譜，當中的訊號源自它們的蛋白質和核酸。那樣，這項研究的重要性在哪?原來血球的形狀和內含物都會隨著血球受損或受壓(under stress)時改變，拉曼鑷子能偵測這些改變的能力因此使其可以準確地診斷出血球異常的情況。

藉由這篇文章，我希望你能欣賞到:就算是一個足以獲得諾貝爾物理學獎殊榮的技術，也同樣能為其他領域帶來巨大的影響。在這例子中，光學鑷子為生物學家帶來了一個寶貴的工具，使他們能以前所未有的方式分析細胞。你還想到其他例子嗎?


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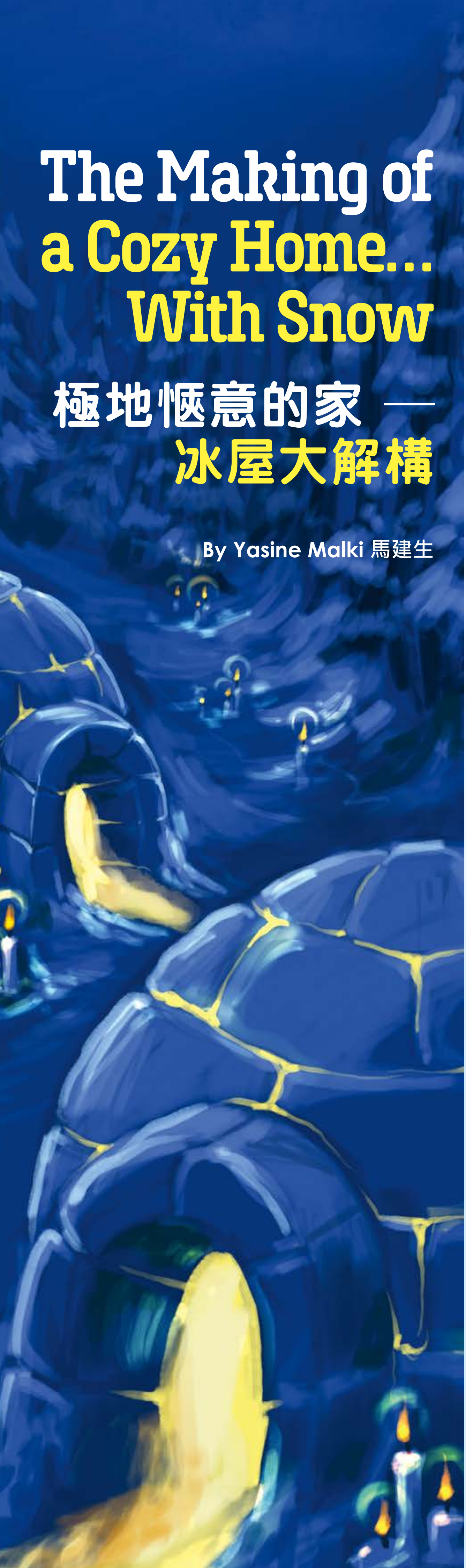
# The Making of a Cozy Home... With Snow

# 極地愜意的家 — 冰屋大解構

By Yasine Malki 馬建生



Imagine roaming around the frozen Arctic all day, at –30 to –40 degrees Celsius with powerful winds blasting around you. There are no trees or other materials nearby to build a cozy wooden house, and all you see is snow. But that's exactly what you need to survive in this harsh environment...by building an igloo!

Igloos have been the Inuit's[1] main shelter, allowing them to survive in the Arctic for 4,000 years [1]. Our intuition tells us that igloos should not work — how could snow be used to build such warm stable dome structures? This may be a mystery to most people, but it can, in fact, be explained by simple physics!

## How to Build an Igloo?

Igloos are essentially built from a collection of snow blocks, which are usually extracted from the ground using long blades and knives. A skilled igloo builder stacks these snow blocks in spirals. The builder will shave a slight incline on the top of blocks so that they tilt inwards after each spiral, until the entire dome-shaped structure is complete [2-4].

To construct a sturdy igloo, two aspects are critical. First, the type of snow used has to be dense, dry and compressed [5]. This tends to be deeper ground snow, between the very fragile fresh snow and the heavy, dense ice.

The second is the shape of the dome: a stable igloo should have a cross-sectional shape of a parabolic arch rather than a semi-circle. A parabolic arch is perfectly optimized to minimize structural tension and maximize compression, which is vital for building with a weak material like snow. In other words, its geometry ensures all the snow blocks exert a force to squeeze themselves together, making it one of the

假如你在北極漫遊了一整天，北風在你身旁颼颼地吹著，溫度只有大約攝氏零下 30 至 40 度。四周沒有樹，亦沒有其他材料讓你興建一座愜意的小木屋。你眼前除了雪之外，也就只有雪。但這正是你在如此嚴峻環境下所需要的救命稻草 — 就蓋一座冰屋吧！

冰屋一向都是因紐特人[1]的主要居所，使他們能在北極地區生活近四千年 [1]。然而直覺告訴我們：冰屋大概行不通吧 — 雪又怎能夠被用於建造一座溫暖的拱形建築呢？不少人心裡仍抱有這樣的疑惑，但其實我們可以用簡單物理解釋箇中原理！

## 如何蓋一座冰屋？

冰屋基本上是由一系列的雪磚蓋成的，當中的雪磚通常是用長刀從雪地中切出來的。一名熟練的冰屋技工會把這些雪磚螺旋形地疊起，他們會在雪磚的頂部切一個小小的斜面，令每一圈的雪磚疊起來都會稍稍向內傾斜，直到整個圓拱形結構完成為止。

要興建一座牢固的冰屋，有兩方面是至關重要的。第一，使用的雪必須是高密度、乾身和壓實的 [5]。這通常是雪地中稍為深的雪，位置處於新鮮粉雪和高密度的冰之間。

第二是拱形結構的形狀。以一座結構穩定的冰屋來說，切面形狀應該是像一條向上的拋物線，即稍為尖的半圓，而不是一個均勻的半圓。拋物線狀的拱形能完美地把結構張力減至最小，並使擠壓力最大化，這對於用雪這些脆弱材料來建屋是十分重要的。換句話說，這種幾何形狀能確保每一層的雪磚都能施力把其他雪磚壓得緊緊的，使其成為最穩固的形狀之一 [5]。相反，均勻半圓的拱形結構當中含有一些高張力的位置（見***圖一***），當中的雪晶（雪花）會被拉開，令冰屋很容易因為些微的外力而倒塌 [5]。

most stable shapes [5]. Meanwhile, a semi-circled arch contains certain sites of higher tension (as indicated in ***Figure 1***), in which the snow crystals are pulled apart, causing the igloo to collapse easily with a little force [5]

***Figure 1.*** *Force trend arrows showing the resultant force direction in a semi-circled shape with blocks of high tension and instability shown in white (left), and a parabolic arch shape (right) [5].*

***圖一*** *箭咀表示在均勻半圓(左;白色雪磚為高張力的不穩定雪磚)和拋物線狀(右)的拱形中合力的方向 [5]。*

## How Does Igloo Keep Us Warm?

Now that we know how an igloo is built, but how exactly does the snow keep us warm?

First we need to clear a misconception — the terms "hot" and "cold" are relative, simply used to describe our perception as a result of heat transfer; (at most of the time) we feel cold when the body loses heat to the surroundings [6]. Therefore, our goal is to create a space that is thermally insulated from the freezing environment.

Igloos are perfect structures for preserving heat. This is primarily due to the property of compressed snow blocks: they are filled with air pockets and contain up to 95% of trapped air [2], making them an excellent thermal insulator. In addition, snow is a very reflective material which can reflect heat inwards in the form of infra-red radiation. Hence, the body heat radiated from a person inside the igloo can be retained very efficiently, as the heat loss through conduction and radiation is minimized. As expected, the temperature inside the igloo can easily be raised with more people, or by using oil lamps or candles to increase the heat release.

Other than conduction and radiation, Inuits also take advantage of their knowledge of the third method of heat transfer, convection, to prevent heat loss. You may have heard of the fact that warm air rises, and cold air sinks. With this phenomenon in mind, igloos are constructed with a sunken entrance tunnel, with areas of snow dug down, and raised sleeping and living platforms [2, 7-8]; thus, the heavier cold air sinks towards the lower entrance area, and the upper area, where the Inuits sleep and reside in, are surrounded by warmer air. In addition, the sunken tunnel can also prevent chill wind and snow from blowing in directly [2, 3, 8].

Collectively, all these factors could lead to an indoor temperature of close to 15°C inside the igloo [1, 7-8] even with an outdoor temperature of around −45°C!

With the laws of physics at play in the igloo's architecture, one can live in a comfortable and cozy snow home in the freezing Arctic.

[1] The two groups of people, Inuit and Yupik, are often referred as Eskimo. Nevertheless, the term "Eskimo" may be considered pejorative because it is associated with the meaning of "eater of raw meat." [9]

## 冰屋怎樣使我們溫暖?

現在我們知道冰屋是如何搭起的,但它實際上怎樣能使我們保持溫暖?

首先我們要先釐清一個誤解 —「冷」、「熱」這兩個詞是相對的,用來描述熱傳遞(heat transfer)為我們所帶來的感覺:(在大多數情況下)當身體的熱流失到四周環境時,我們感到冷 [6]。因此,我們的目標是製造一個冷熱上絕緣的空間,把我們與寒冷的環境隔開。

冰屋是把熱留住的絕佳結構。這主要是因為那些壓得實實的雪磚:它當中有很多氣囊把空氣困住,一塊雪磚的空氣含量甚至能高達 95% [2],使它們成為優良的熱絕緣體。此外,雪是一種反射性強的物料,能把熱以紅外線的形式向冰屋內反射。因此,從人體散發的熱能被非常有效地留住,經傳導和輻射散失的熱因而大大減少。與我們所料的一樣,更多人在冰屋裡面,以及在冰屋裡面使用油燈和蠟燭都能輕易地使冰屋內的溫度上升,因為釋放更多熱。

除了傳導和輻射,因紐特人還善用了他們對熱傳遞的第三個方法 — 對流的知識來減少熱的流失。你可能已經知道熱空氣會上升,冷空氣會下降的事實。因紐特人亦深明這個道理,因此他們會在入口處把地面的雪挖走,建造一條比地面稍低的隧道作為入口,也會把睡覺和活動的地方建在一個比地面稍高的位置 [2, 7-8],令較重的冷空氣向較低的入口處下沉,他們睡覺和居住的上層則被暖空氣所包圍。另外,下沉的隧道還可以避免刺骨的寒風直接吹進屋內 [2, 3, 8]。

綜合來說,即使戶外的溫度約為 −45°C,這些方面的措施都可以令冰屋內部有著接近 15°C 的氣溫 [1, 7-8]!

冰屋的建築正是因為有著在物理定律上的各種考量,才能讓人即使在冰封的北極,亦能住進一個舒適愜意的家。

[1] 因紐特人(Inuit)和尤皮克人(Yupik)這兩群人通常都被統稱為愛斯基摩人(Eskimo)。可是,愛斯基摩人這個詞語的本意為「嗜生肉的人」,因此有時會被視為帶有貶義的稱呼 [9]。

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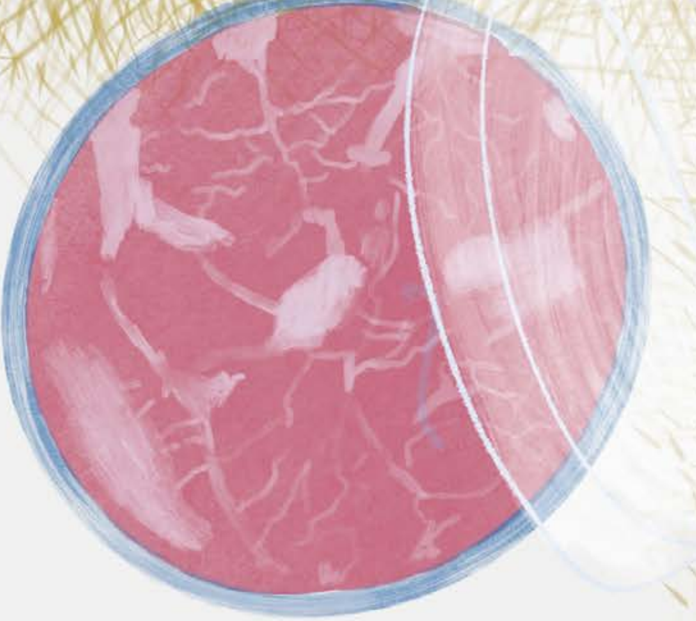
# Cultured Meat: The Future of the Meat Industry

**By Chantelle Sullivan 蘇盈安**

In the prehistoric ages, hunters made weapons to aid in their pursuit of prey for food. But with the passage of time, humans' expanded wealth of knowledge led to animal domestication, artificial selection and genetically modified (GMO)-meat. To fulfill the demands of an ever-increasing population in the modern world, factory farming in the meat industry has become the norm for obtaining meat. However, this process equates to misery and suffering for many animals involved, and places a tremendous burden on the environment. Meat production accounts for the use of a surprising 26% of the Earth's ice-free land area [1], 27% of global freshwater consumption [2] and 18% of total human-caused greenhouse gas emissions [3]. Seventy-four billion land animals are killed every year just for human consumption [4]. It was estimated that every kilogram of beef requires 25 kilograms of grain and 15,000 liters of water [5]. Deforestation constantly occurs in areas such as the Amazon rainforest to make space for beef farming [6]. However, animal products only accounts for 18% of the calories and 37% of the protein that humans consume, proving it to be an inefficient food production system [7]. With climate change, limited resources and environmental pollution becoming pressing problems in today's world, more innovative methods are required to avoid the negative environmental impact caused by factory farming. The emergence of cultured meat can potentially be the solution in rendering factory farming obsolete, acting as a more environmentally friendly, sustainable and healthy replacement.

Many biotechnology start-ups are working on developing cultured meat on a large scale. The process involves obtaining satellite cells from an animal's muscle. Also known as muscle stem cells, satellite cells have the potential to divide and differentiate into different subtypes of muscle cells when they detect muscle injury. They are also activated for muscle hypertrophy, which is the process of muscles growth and enlargement after consistent, intensive exercise. Once plated in growth media, the satellite cells divide and differentiate into muscle cells, which double in number every few days. When a sufficient number of cells are reached, they are guided into forming strips through the use of scaffolds[1]. These scaffolds mechanically stretch the cell layers to induce further growth and increase in their protein content, just like the muscles that are normally found in animals. Certain companies have incorporated the use of bioreactors to encourage larger scale growth of such muscle fibers. Current research is also looking into combining fat cells into the layers to produce a more authentic meat flavor, since muscle cells alone will be rather tasteless, very tough and chewy.

# 「種」出人造肉 ——
# 未來的肉類生產方法？



Although cultured meat may sound like a great replacement of meat production at first glance, further refinements have yet to be made to increase the sustainability of the process. Cultured meat start-ups around the world are looking into solutions to tackle the current longstanding problems. First, growing meat (which contains muscle and fat cells) in the laboratory requires vast amounts of fetal bovine serum (FBS) — the conventional supplement in growth medium used for culturing cells in the lab, which contains growth factors, proteins, vitamins and other substances required for optimal cell growth. It is also subject to widespread criticism and negativity, since it is extracted from the heart of calves by a cardiac puncture without anesthesia, following the slaughter of pregnant cows [8]. Since FBS is a byproduct of factory farming, ongoing research is carried out on looking for serum-free alternatives to grow cultured meat. A study conducted by Fujita et al. showed the promise of using serum-free media for growing myoblast cells [9]. Myoblasts are descendants of satellite cells. They have the ability to fuse to form myotubes, a multi-nucleated, elongated structure which indicates they are on the right developmental track towards differentiating into mature muscle cells. Some scientists are venturing towards the search for suitable plant-derived growth supplements to replace FBS for cell culture. Such research paves the way for the possibility of cultured meat to be commercialized.

Another problem lies in the scaffold required for the orderly three-dimensional growth of cells — another hurdle for scientists in the cultured-meat industry to overcome for easier meat production. IntegriCulture, a Japanese biotech start-up which focuses on developing cell-based meat, has suggested the possibility of using edible materials, such as sponge collagen, chitosan[2] and chitin, as scaffold [10]. In fact, earlier in 2009, scientists have found the microporous collagen-chitosan, a material prepared by combining collagen and chitosan, to be a suitable scaffold for the proliferation of fibroblasts, a type of connective tissue cell [11]. Research from the Chinese University of Hong Kong has also shown that the collagen-chitosan scaffold enhanced the growth and division of rat stem cells from their bones [12]. Although this mixture of scaffold has yet to be tested amongst satellite cells, it is undoubtedly an area that deserves more investigation.

While there is still a ways to go before cultured meat could become the norm for satiating meat lovers around the world, the progress made in this industry thus far is promising! Start-ups are blooming in the United States, Europe and Southeast Asia, with a focus on slaughter-free methods of meat production. The rate of consumer acceptance for cultured meat is also encouraging. The ability to produce cultured meat holds much excitement even for us, as it means we can delight in the possibility of consuming delicacies from sashimi-grade fish to plump Peking duck, without harming animals nor the environment.

[1] Scaffold: A structure that provides proper surroundings and mechanical support for the cells to grow onto it. It also guides the tissue to grow into the desired shape.

[2] Chitosan: A polymer derived from chitin, a substance which makes up the shells of crustaceans, e.g. crabs and shrimps.

在史前時期，為了果腹，獵人製造武器協助他們狩獵。隨著時間的推移，人類的知識變得豐富，帶來了畜牧、選擇育種和基因改造肉類。為了應付現今社會不斷膨脹的人口所帶來的肉類需求，透過工廠化飼養（factory farming）取得食用肉變成了肉類行業的常態。可是，這個過程少不免會為動物帶來痛苦，亦為環境帶來沉重的負擔。肉類生產出乎意料地佔用了地球陸地面積（被冰覆蓋的陸地除外）的 26% [1]、全球淡水用量的 27% [2] ，以及佔人為溫室氣體排放的 18% [3]。僅是供人類食用而被屠宰的動物每年就有 740 億隻 [4]。據估計，生產每公斤牛肉需要 25 公斤穀物和 15,000 公升水 [5]；為了騰出空間飼養牛隻，人們還經常會在亞馬遜雨林等地區進行伐林活動 [6]。然而，動物產品只佔人類攝取熱量的 18% 和攝取蛋白質的 37% ，可見這是一個低效率的食物生產系統 [7]。當氣候變化、資源稀少和環境污染已經變成世界今天切身的問題時，我們需要找尋更多創新的方法避免工廠化飼養所導致的環境問題。人造肉的誕生有望能使工廠化飼養成為歷史 —— 它是一個更環保、可持續和有益的替代方案。

不少生物科技初創企業致力於研究大規模生產人造肉。過程涉及從動物肌肉中抽取衛星細胞，又名肌肉幹細胞。它們可以在發現肌肉受傷後分裂及分化成肌肉細胞，亦可以通過被活化而參與肌肉肥大的過程；肌肉肥大是指肌肉在有規律的高強度運動後生長和變大的過程。一旦被放置於含有培養液的容器上，衛星細胞會分裂並分化成肌肉細胞，細胞數量每過數天便會翻倍。當細胞達到一定數量時，它們可以在支架[1] 的引導下形成條狀組織。支架會對細胞層施加拉力，刺激其作進一步生長和增加蛋白質含量，就像正常的動物肌肉一樣。有些公司還把生物反應器用於過程中，以更大型生產這些肌纖維。現時的研究亦嘗試把脂肪細胞加入這些肌肉細胞層之間，希望製造出更真實的肉味，因為肌肉細胞本身吃起來並沒有味道，而且非常韌和難嚼。

雖然驟眼看來人造肉似乎是肉類生產上一個不錯的替代辦法，但我們還需要繼續改進其生產過程以增加可持續性。世界各地研究人造肉的初創企業都在不斷嘗試找尋方法，以解決現時一些存在多時的問題。首先，在實驗室培養肉類（當中包含肌肉和脂肪細胞）需要使用大量的胎牛血清（fetal bovine serum/FBS）。胎牛血清是在實驗室的細胞培養中慣常會加入培養液的補充品，它含有生長因子、蛋白質、維他命和其他對細胞生長有利的物質，為細胞提供最適合的生長環境。但胎牛血清的使用亦受到廣泛的批評，因為胎牛血清提取的方法是在屠宰懷孕的母牛後，在沒有麻醉的情況下通過刺穿小牛的心臟而取得的 [8]。由於胎牛血清仍然是工廠化飼養下的副產物，科學家正進行研究並希望找出一些不含血清的替代品來培養人造肉。由藤田等多位科學家進行的實驗則展示了利用不含血清的培養液來培養肌原細胞的可能性 [9]。肌原細胞是從衛星細胞分化而成的，它們能夠結合而形成名為肌小管（myotube）的結構，出現這個多核的長條狀結構表示肌原細胞正朝著正確發育方向進一步分化為成熟的肌肉細胞。科學家們正在尋找合適的植物性補充品在細胞培養中代替胎牛血清，這類研究都有望為人造肉創造更有利的條件推出市場。

另一道難題在於能協助細胞有規律地生長成立體形狀的支架；要更簡易地生產人造肉，科學家必須克服當中的困難。IntegriCulture 是日本一所研發細胞性肉類的生物科技初創企業，他們提出了以不同可食用物質來製造支架的可能性，比如是膠原蛋白海棉、幾丁聚糖[2]（chitosan；又名聚殼糖）和幾丁質（chitin；又名甲殼素）[10]。其實早於 2009 年，科學家已經發現一種名為「膠原蛋白—幾丁聚糖」的材料是作為纖維母細胞（fibroblast）支架的合適材料，它能使結締組織細胞之一的纖維母細胞增殖（proliferation；即快速分裂）[11]；這種具有微孔的材料由膠原蛋白和幾丁聚糖混合而成。香港中文大學的研究亦顯示「膠原蛋白—幾丁聚糖」支架能促進一些從骨抽取的大鼠幹細胞生長和分裂 [12]。雖然尚未有測試把這種混合物製成的支架用於衛星細胞上，但這無疑是未來一個值得研究的方向。

儘管現在與能用人造肉來滿足世界上所有「食肉獸」的一天還十分遙遠，但至少到現時為止這方面的進展仍相當理想！同樣是研究著不涉及屠宰的肉類生產方法，來自美國、歐洲和東南亞的初創企業都發展蓬勃；消費者對人造肉的接受程度也是令人鼓舞的。然而，最值得興奮的其實是能夠製造人造肉這個事實本身，因為它意味著我們可以在不傷害動物和環境之下，享用到各式各樣的葷食佳餚 —— 不論是刺身級數的魚肉，又或者是脂香豐滿的北京烤鴨。

[1] 支架：一個為細胞提供適當環境和物理支撐的結構，令細胞可以依附並在上面生長，亦能引導組織生長成理想的形狀。

[2] 幾丁聚糖：一種由幾丁質衍生的聚合物；而幾丁質是組成甲殼類動物（蝦、蟹等）外殼的物質。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By Sonia Choy 蔡蒨珩

# Hungry Mathematicians and the Ham Sandwich

# 肚餓的數學家與他們的火腿三文治

Mathematicians like their food (a lot). There are theorems about numbers, functions, circles, triangles — and theorems about pizzas, potatoes, cakes, pies, donuts and sandwiches. We'll visit one of these here — the Ham Sandwich Theorem, a problem on sandwich-cutting proposed in the late 1930s [1].

There's an ongoing debate whether cutting a sandwich into triangles or rectangles is the right method; however, we are considering something a little less aesthetically pleasing — what if your little brother has nipped off a corner of your sandwich, or the piece of ham inside has been folded into some odd shape? No matter what the shape of the sandwich is, can you still divide the sandwich into two equal halves, to be shared amongst two hungry people?

## Our Tool: The Intermediate Value Theorem

It might sound absurd, but mathematics tells us that no matter how irregular the shape of the sandwich is, there is always a way to cut the sandwich into two equal halves in one cut. This is due to a result in calculus called the Intermediate Value Theorem (IVT). Now that I've said the C-word, however, don't run away just yet — ***Figure 1*** can help you visualize it.

We will only look at the part of the graph that is between *a* and *b*, which generates the function values *f(a)* and *f(b)*. Basically, the Intermediate Value Theorem tells you that there is always a number *c* between *a* and *b* (on the x-axis) that produces a number between *f(a)* and *f(b)* (on the *y*-axis) [2] [1].

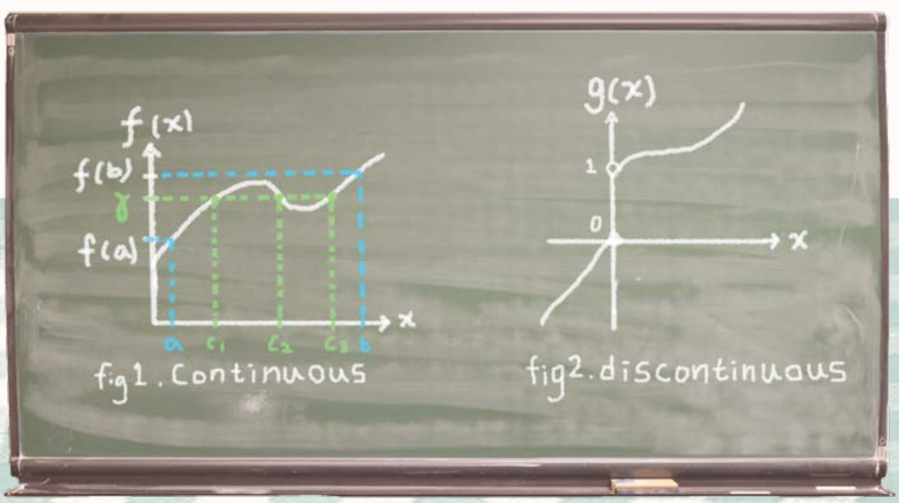
IVT looks intuitive from a graphical point of view — think of the curve as a mountain. If we start at sea level, at the foot of a 200m hill and climb up to the top, at some point we are bound to pass a point that is at 100m above sea level. We will not go into the details of the intimidating math here, but this is the general idea and what we need for this argument.

One thing to note though is that IVT requires the function to be continuous, which means that it doesn't break open in the middle. You can see this in ***Figure 2***; you can never find a number x for which *g(x)* is between 0 and 1, since the function has a sudden jump in the middle.

## The Solution

So what does it have to do with cutting our ham sandwich into two equal halves? It turns out that all we have to do to solve this problem is to apply IVT.

More conveniently, we will first consider the two-dimensional case, which is a problem of slicing two flat pancakes into two equal halves. You may have learned already that a line can be described by its slope, tan(*α*), where *α* is the angle it makes with the positive x-axis, and its *y*-intercept, *c*.



# Hungry Mathematicians and the Ham Sandwich

# 肚餓的數學家與他們的火腿三文治

數學家(十分)喜歡他們的食物。除了關於數字、函數、圓形和三角形的定理 — 你有沒有想過原來也有定理是關於薄餅、馬鈴薯、蛋糕、餡餅，甜甜圈和三文治的？我們今天會探討其中一個問題，它是在 1930 年代提出的火腿三明治定理。

大家也許會為著應該把三文治切成三角形還是長方形而爭持不下；然而，讓我們暫且把美學方面的問題擱在一旁 — 試想想，當弟弟把你的火腿三文治咬了一角，又或者裡面的火腿摺疊成某個奇怪的形狀？在任何奇怪的形狀下，你還能把三文治分成兩等份以餵飽兩個餓得肚子打鼓的人嗎？

### 我們的工具：中間值定理

這聽起來可能不可思議，但是數學告訴我們無論三文治的形狀如何不規則，我們都總有辦法只用一刀把三文治分成兩等份。這結論是由微積分中「中間值定理(Intermediate Value Theorem/IVT)」所得出來的結果。剛才我說了那個令人生畏的詞語，但請不要聽到「微」字就逃跑！***圖一***能幫助你理解這個定理(見前頁)。

我們關注的只是圖表中從 $a$ 到 $b$ 的部分，它們所對應的函數值就是 $f(a)$ 和 $f(b)$。簡單來說，中間值定理告訴你 $a$ 跟 $b$ 之間($x$ 軸)一定有著一個數字 $c$，它能產生 $f(a)$ 和 $f(b)$ 之間($y$ 軸)的任何一個值 [2] [1]。

從圖像來看，中間值定理其實不難明白 — 我們可以把曲線看成一座山。如果我們從海平面的高度開始爬上一座 200 米高的山，並一直爬到頂峰，在路途中的某個時候我們一定會經過高度為海拔 100 米的一點。數學上頗為嚇人的細節我就不解釋了，但這就是中間值定理的基本概念，亦是我們在論證過程所需要的。

一個要留意的地方是中間值定理只適用於連續函數，即是中間不會「斷開」的函數。你看***圖二***就能夠理解了，你不能找到一個數字 $x$ 來對應 $g(x)$ 為 0 至 1 之間的值，因為這個函數在中間忽然「跳」了一下。

### 題解

說到底，中間值定理到底跟把三文治切成兩等份有甚麼關係？要解決這個問題，原來我們要做的就是應用中間值定理。

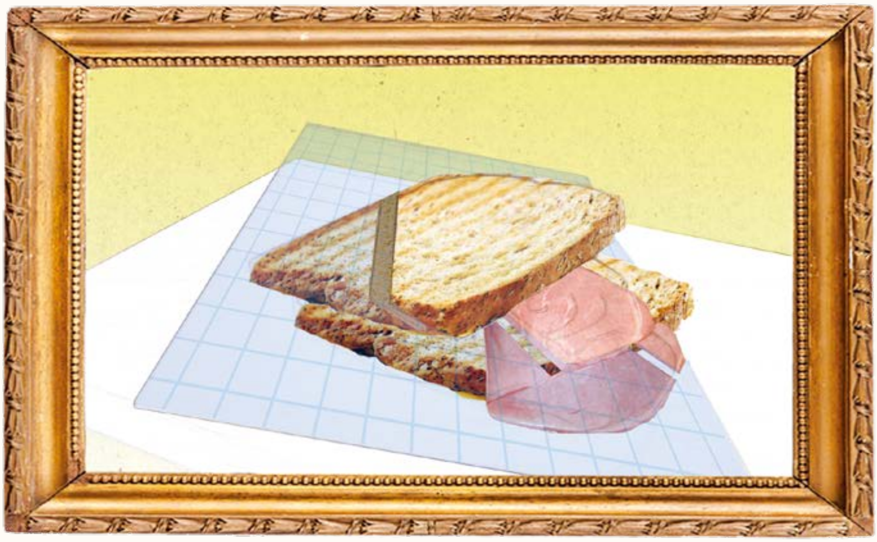
為了方便大家理解，我們可以先考慮二維的例子：一個關於如何把兩塊平面熱香餅平分的問題。你可能已經學過，一條線可以用它的斜率 $\tan(\alpha)$ ($\alpha$ 是線跟正 $x$ 軸之間相交的角度) 和 $y$ 軸截距 $c$ 來描述。

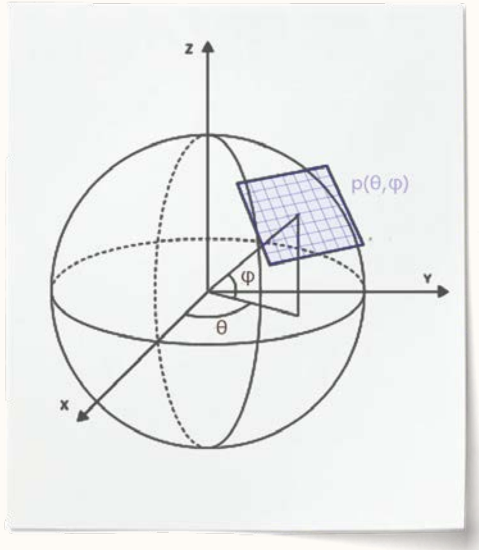
對於每一條斜率為 $\tan(\alpha)$ 的線，無論 $\alpha$ 是任何值也好，我們總可以把它畫成能一條把第一塊熱香餅切成兩等份的線。然後我們需要一個函數來完成我們的論證，最方便的就是取第二塊熱香餅在線兩旁的面積百分比之差作為我們的函數；線就好比我們的刀，取線的右邊，即從刀柄看去的右邊，把其設定為正。譬如說，你看到有 20% 的熱香餅在線的左邊，80% 在線的右邊，那麼我們函數的數值就會是 $-20\% + 80\% = 60\%$ 了。假如我們把 $\alpha$ 旋轉 180 度，函數數值的正負便會倒轉。所以我們可以發現有些 $\alpha$ 數值會讓函數變成負數(較多的熱香餅在左邊)，有些則會讓函數變成正數(較多的熱香餅在右邊)。

如果我們取一對正負相反的函數數值的話，利用中間值定理，我們可以推論出某個 $\alpha$ 的數值將會使 $f = 0$，亦即是說有 50% 的熱香餅在線的左邊，亦有 50% 的熱香餅在線的右邊；所以我們的兩塊熱香餅現在已經被一刀切成兩半了！

現在讓我們返回原本的問題。為了方便理解，我們會把三文治分成三個部分：兩塊麵包和一塊火腿。剛才討論的熱香餅面積則成為了麵包或火腿體積，而代表切割的線亦變成了一塊二維的平面。

讓我們先考慮最上層的麵包。首先請注意到調整一把刀的切面有三個方法：沿垂直軸平移($p$)和沿著兩個角度旋轉，分別是沿著麵包表面($\theta$)和刀的傾斜角度($\phi$)。剛才在二維例子的推論亦可以應用於此，我們可以將兩塊麵






For each line with slope tan($\alpha$), it is possible to draw it such that the first pancake is sliced in half, even for any value of $\alpha$. Then we need a function to complete the argument — here it is most convenient to take the difference in percentages of the area of the second pancake as our function, taking the right hand side of the line, as seen by an observer from the handle of the knife, as positive. For example, if 20% of the pancake lies to the left and 80% of it lies to the right, our function would equal –20% + 80% = 60%. The sign of the function flips when you rotate $\alpha$ by 180 degrees. So we can see that there are values of $\alpha$ where the function is negative (more of the pancake is on the left), and where it is positive (more of the pancake is on the right).

Take a pair of values with opposite signs; by applying IVT, we conclude that there is a certain $\alpha$ which causes $f = 0$, indicating that 50% of the pancake lies to the right and 50% lies to the left of the line. Our two pancakes are now sliced into equal halves in one cut!

And now it is time to tackle our original problem. To simplify things, we'll split the sandwich into its three parts: two pieces of bread and a piece of ham. Now the area of the pancake becomes the volume of the piece of bread/ham, and the cutting line becomes a 2D plane.

Consider the top piece of bread. First note that there are three ways you can adjust a knife: translating along the vertical axis ($p$), and rotating in two angles — along the plane of the bread's surface ($\theta$), or the tilt angle ($\phi$). We can reuse the two-dimensional result above by first treating the two pieces of bread as in the case above, and immediately obtain both p and $\theta$. Before we proceed, we note that both p and $\theta$ can be described as functions of $\phi$ — as $\phi$ changes, p($\phi$) and $\theta$($\phi$) also change accordingly, but both are defined above so that they always cut the first two solids in half.

The final step is to add the piece of ham. We can then consider $f_3(\phi)$, defined as above as being the difference in percentages of the volume of the piece of ham, its variable being the remaining tilt angle, $\phi$. The sign of $f_3$ flips when you rotate $\phi$ by 180 degrees, which gives us a pair of positive and negative values we can take as our boundary points. Then, by the IVT, we know there is a certain value of $\phi$ where $f_3(\phi) = 0$.

Combining the results from all three parts, we then know it is possible that all three pieces are cut into half, which is exactly what we want!

包用上文提及方法處理，然後得出 $p$ 和 $\theta$。在繼續討論之前，要留意的是 $p$ 和 $\theta$ 都能寫成 $\phi$ 的函數：隨著 $\phi$ 數值的改變，$p(\phi)$ 和 $\theta(\phi)$ 也會相應地改變；然而根據上面的定義，兩者都總能把兩塊麵包平分。

最後我們加上火腿。像上例一樣，我們取切面兩邊火腿體積百分比之差作為我們的函數 $f_3(\phi)$，其變數是最後剩下的傾斜角度 $\phi$。當我們把 $\phi$ 旋轉 180 度，$f_3$ 的正負號便會倒轉，這能提供正負各一的數值作為我們的邊界點。然後根據中間值定理，我們知道確實存在某 $\phi$ 值能使 $f_3(\phi) = 0$。

綜合三個部分的結果，我們知道確實可以使三文治的三個部分都平分成一半 —— 這正是我們想要證明的結果！

> 有些讀者可能對於論證中變數的連續性有所懷疑。的確，中間值定理並不保證當中的連續性；所以比較準確的證明是使用代數拓樸學中的著名的 Borsuk–Ulam 定理，它可以說是中間值定理的簡單歸納，但由於它涉及稍為艱深的數學，我暫且在此擱筆。如果你有足夠勇氣的話，請看下面是火腿三明治定理的另外一個證明：
>
> Borsuk–Ulam 定理保證 $f(\phi)$ 在某個時候會等於 $f(-\phi)$，當中的負號代表我們的刀「反轉」（即旋轉 180 度）— 所以這個關係成立的唯一一個情況就是當我們考慮的那一層被切成一半的時候。因此，在分別寫出火腿和其中一塊麵包的體積差函數之後，我們便能直接宣稱存在某 $p(\theta, \phi)$ s.t. $f_2(p) = f_3(p) = 0$，也就是我們考慮的兩層被分成兩等份了。

### 換個角度想想……

如果上面的詳細證明已經令你看不下去的話，其實也可以把這個問題看成一個數數目的問題。三件立體的體積都由三個維度組成，稱作 $x$、$y$ 和 $z$ 軸，所以體積是一個包含三個變數的函數：長 ($x$)、寬 ($y$) 和高 ($z$) —— 亦即是你要兼顧三個變數。當嘗試解聯立三元方程，而當中每個未知數都取決於其他未知數的時候，我們最多可以加上三個非重疊的條件來取得解[2]。這在邏輯上與我們的問題很相似：要求到解的話，我們最多只能加上三個條件；就我們的情況而言，把三個立體平分正是我們的三個條件，所以我們能求到解。透過比較維度的數目（三個未知數，三個限制），我們可以亦解決這個問題。

### 火腿三明治定理

把以上的推論歸納一下，我就能得出火腿三明治定理本身的描述：假設在 $n$ 維空間中有 $n$ 個物件，必定存在一個 ($n - 1$) 維的超平面[3] 能同時把 $n$ 個物件平分成一半。就我們的情景而言，我們考慮的是日常的三維空間 ($n = 3$)，因此這個定理告訴我們的是：我們能用一個二維的平面把三件物件平分，當中切割面是由我們的刀所產生的。

根據這個描述，讓讓我們再看一看另外一個例子吧。小斌很喜歡吃芝士，他把一塊芝士加到三文治中間。這動作看起來好像並不會帶來甚麼影響，但這我們可能因此再不能把三文治平分成兩半了。從火腿三文治定理的描述來看，我們知道只有三樣物件，而不是四樣，能保證被一個二維平面平分。再想想看，我們能把刀控制的變項也只有三個。

最後你可能會問一個問題 — 到底我們應該怎樣把眼前的三明治切成一半呢？答案是：我也不知道！中間值定理只告訴我們如此把三文治切成一半的方法存在，但它並沒有提及切三文治的方法。換言之，如果你的三明治被弟弟咬了一口的話，也許你應該再做一份三文治才跟你的朋友分享吧！

1 對於有數學天份的讀者，中間值定理的正式論述是：假設 $f(x)$ 在 $a$ 和 $b$ 之間是連續的，若一個任意數 $\gamma$ 滿足 $f(a) < \gamma < f(b)$ 或 $f(b) < \gamma < f(a)$，則存在一點 $c$，而 $a < c < b$，使 $f(c) = \gamma$。[2]

2 有些讀者可能察覺到不是所有聯立三元方程也有解，譬如說很明顯地，$x + y + z = 1$、$x + y + z = 2$ 及 $x + y + z = 3$ 這組方程並沒有解。這純粹是一個類比手法，而用中間值定理證明的話能保證一定是會有解的。

3 超平面：一個比環繞空間少一個維度的子空間；在我們關於平分火腿三文治的討論中，這個超平面是指普通的二維平面。

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Some readers might have questions about the continuity of the argument. Admittedly, the continuity of the argument here is actually not guaranteed by IVT; it is more accurate, instead, to use the Borsuk-Ulam Theorem, a famous result from algebraic topology that can be described as a sweeping generalization of IVT. I will not dive into the details here, as it involves quite a bit of difficult mathematics. For the intrepid reader, here is the alternate proof for our ham sandwich problem:

The Borsuk-Ulam Theorem guarantees some point where $f(\phi) = f(-\phi)$, the minus sign being our knife "switching sides" (rotating by 180 degrees) — so the only case in which this relation holds is when the solid is cut into half. In this case, setting up two volume functions for the ham and bread respectively, we can directly claim the existence of $p(\theta, \phi)$ s.t. $f_2(p) = f_3(p) = 0$, so the two solids are bisected.

## *An Alternative Way of Thinking*

If you don't want to dive into the nitty-gritty of the math here, it's possible to view this problem as a counting problem. The volume of each of the three solids is made up of three dimensions — namely the x, y and z axes, so the volume is a function of three variables — length (x), width (y) and height (z). There are three different variables you can control. When solving simultaneous equations in three unknowns that depend on each other, one can at most impose three non-overlapping conditions in order to get a solution[2]. This is a similar logic to the puzzle above: we can only impose at most three conditions, in this case dividing each of the solids into half, for which there is a solution. By comparing the number of dimensions (three unknowns, three constraints), we can solve the problem.

## *The Ham Sandwich Theorem*

Generalizing this logic, we can arrive at the statement of the Ham Sandwich Theorem itself: given *n* objects in *n*-dimensional space, there exists an (*n* – 1)-dimensional hyperplane[3] that simultaneously cuts all *n* objects in half. For our case, we are dealing with day-to-day, 3D space (*n* = 3); the theorem says that we can cut three objects in half by a 2D plane, in our case the cutting plane created by our knife.

We'll test this statement out with a second scenario. Suppose Bob is craving cheese, and he adds in a piece of cheese to the sandwich. However, this seemingly insignificant act might make our task of dividing the sandwich impossible. From the theorem's statement, we know that only three objects, but not four, can be divided by a two-dimensional plane. As a reminder, there are only three variables we can control about the knife.

One last note — so how exactly should we cut this sandwich up? We don't know. IVT only tells us that such a way to cut the sandwich exists; it doesn't mention the way you can cut it up at all. In other words, if your little brother has taken a bite from your sandwich, it's probably a better idea to make a new one for the friend you intended to share your sandwich with!

[1] For more mathematically inclined readers, the formal mathematical statement says: If f(x) is continuous between *a* and *b*, then for any number *y* satisfying $f(a) < y < f(b)$ or $f(b) < y < f(a)$, there is a number c satisfying $a < c < b$ and $f(c) = y$. [2]

[2] Some readers might note that not all sets of three equations in three unknowns can be solved (for example, the system $x + y + z = 1$, $x + y + z = 2$ and $x + y + z = 3$ is clearly unsolvable). This is purely an analogy; the mathematical argument using IVT guarantees a solution.

[3] Hyperplane: A subspace which is one dimension less than its ambient space; in our case about bisecting the ham sandwich, it is just a regular 2D plane/surface.

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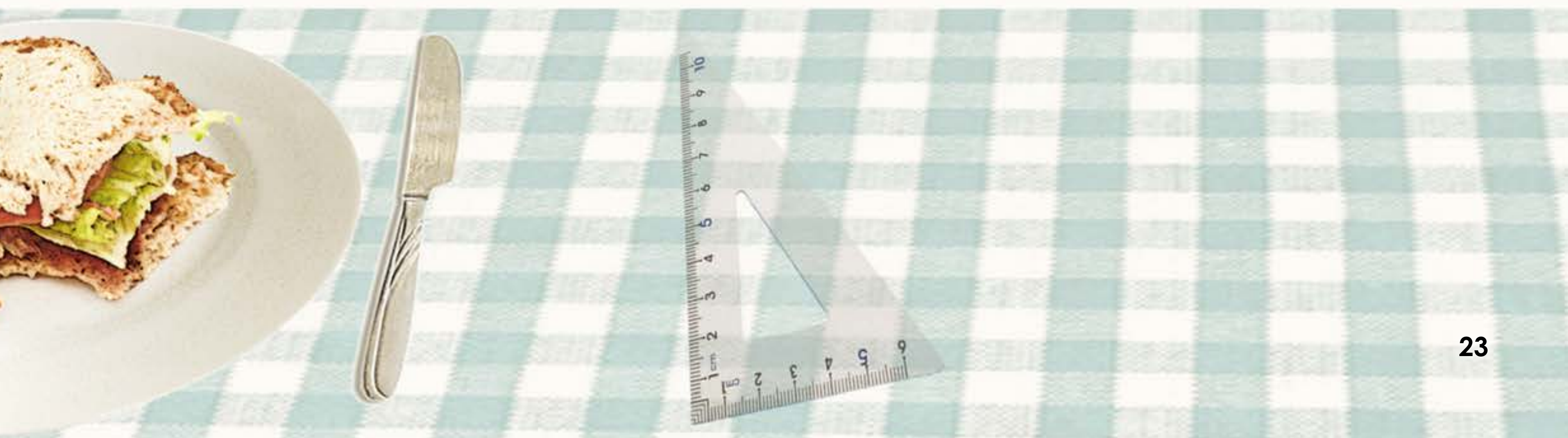


Washing hands before meals and cleaning homes with bleach are some of the common practices people follow to get rid of germs. While most people associate microorganisms with diseases and infections, they are actually crucial to our health. Our digestive tract contains trillions of microbes with up to 1000 species from bacteria, archaea, fungi, and protists that aid digestion and help maintain other body functions [1]. Gut microbiota also plays important roles in other animals. For example, although herbivores have a plant-based diet, not all of them are capable of digesting the cellulose in their diet on their own. Symbiotic bacteria are often required to break down cellulose to extract glucose for energy.

While humans, as omnivores, do not rely entirely on breaking down cellulose for energy, our gut microbiota still plays an essential role in our digestion and metabolism. The microbiota is capable of fermenting indigestible dietary fibers into short-chain fatty acids (SCFAs), which makes up around 10% of our daily caloric requirement and serve as the major energy source for cells lining the colon [1]. Not only do the SCFAs serve as an energy source, but they may serve as signals that modulate the ability of human cells to handle fat and sugar.

Maintaining the gut microbial diversity and balance is crucial to our health. Low gut bacterial diversity is correlated with inflammatory bowel disease, diabetes and obesity [2]. In some cases, antibiotic therapy disrupts the original gut microbiome and causes the proliferation of the opportunistic pathogen, *Clostridium difficile*, which leads to diarrhea and inflammation of the colon. Fecal microbiota transplantation (FMT) — transplantation of feces (with microbiota) from a healthy donor to the patient's colon — has been proved effective to the patients experiencing devastating and recurring *C. difficile* infection [3]. Although it does not sound aesthetically appealing, it helps cure the disease by restoring the ecology of the gut microbiome.

Besides, the association between specific microbes and obesity were also discovered. The bacteria under the genus *Christensenella*, which was rarely found in overweight people [2], has been shown to prevent weight gain in mice [4], while those under *Akkermansia* correlate with lower fat deposition near internal organs in human [5]. Interestingly, however, the colonization of both species was suggested to be influenced by host genetics [4, 5]. In other words, not all of us can provide a "good home" for the beneficial microbes.

# 腸道菌群 — 微生物與我們的健康

# Gut Microbiota — Microorganisms and Our Health

By Kit Kan 簡迎曦

為了消毒殺菌，飯前洗手和用漂白水清潔家居等都是不少人的生活習慣。雖然大部分人都會把微生物與疾病和感染畫上等號，但實際上微生物對我們的健康至關重要。我們的消化道包含數以萬億計的微生物，其中包括多達1000種細菌、古細菌、真菌和原生生物，它們有助於消化及維持其他身體機能[1]。腸道菌群在其他動物中也起著重要作用，例如儘管草食動物的食物是以植物為基礎，但它們不一定能自行消化植物中的纖維素，因此通常需要腸道內的共生細菌分解纖維素以提取葡萄糖來獲取能量。

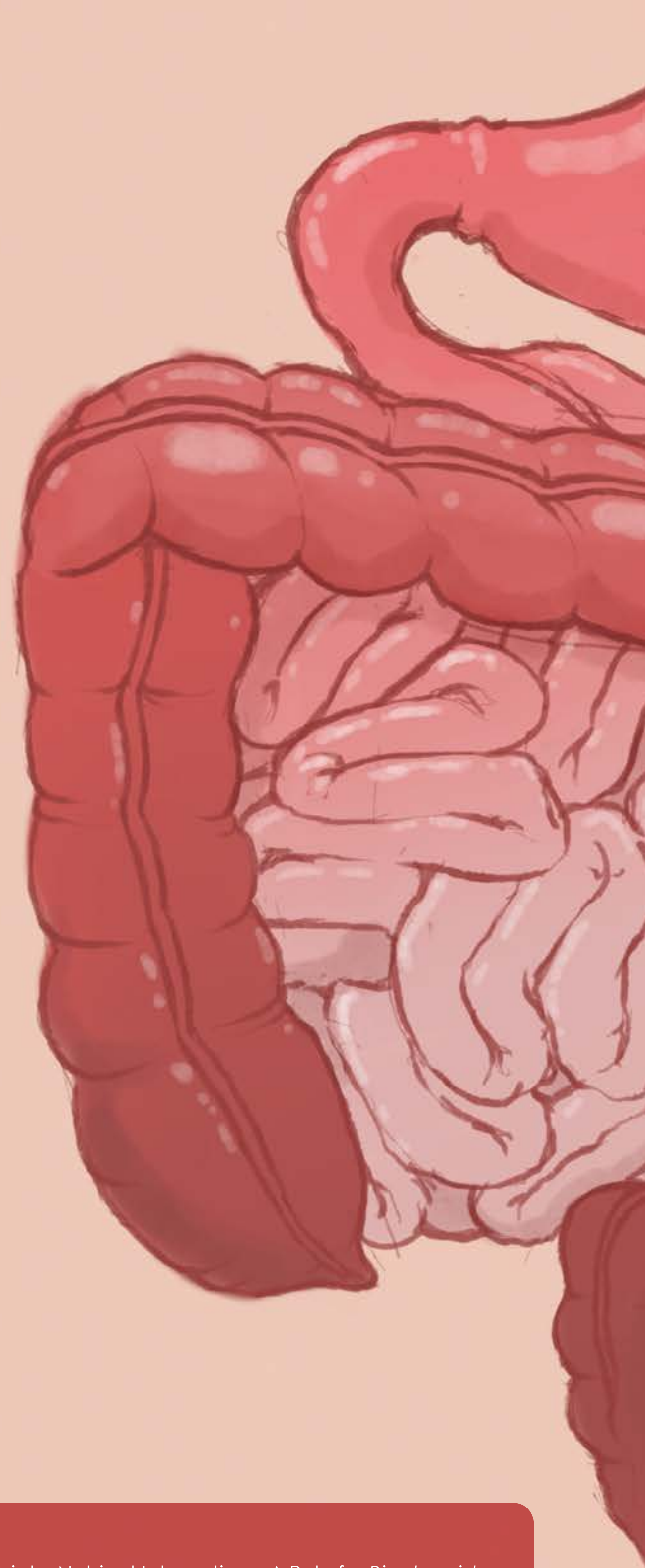
雖然人類作為雜食動物並不需依靠分解纖維素來獲取能量，但我們的腸道菌群仍在我們的消化和代謝中起著至關重要的作用。微生物群能夠將不能消化的膳食纖維發酵成短鏈脂肪酸(Short Chain Fatty Acids/SCFAs)，SCFAs約佔我們每日熱量需求的10%，並且是結腸內壁細胞的主要能量來源[1]。其實SCFAs不僅可以用作能量來源，還可以作為調節人體細胞處理脂肪和糖的信號。

維持腸道微生物的多樣性和平衡對我們的健康十分重要。低腸道細菌多樣性與炎症性腸病、糖尿病和肥胖症有關[2]。在某些情況下，抗生素治療會破壞原本的腸道微生物群系，並導致伺機性病原體艱難梭菌(*Clostridium difficile*)的增殖，從而導致腹瀉和結腸發炎。糞便微生物移植(Fecal Microbiota Transplantation/FMT)是指將糞便(含菌群)從健康捐贈者移植到患者的結腸，這方法已被證明對經歷嚴重和復發性艱難梭菌感染的患者有效[3]。儘管聽起來有點噁心，但糞便微生物移植能夠通過恢復腸道微生物群系的生態來幫助治癒疾病。

此外，科學研究亦發現了特定微生物與肥胖之間的關聯。克里斯滕森氏菌屬(*Christensenella*)的細菌很少在過重的人中發現[2]，研究亦顯示這些細菌可以防止小鼠體重增加[4]；而阿克曼氏菌屬(*Akkermansia*)的細菌則與人體內臟附近的脂肪積聚的減少有關[5]。但是，有趣的是這兩類細菌的定殖(colonization)都受到宿主基因影響[4, 5]。換句話說，並非所有人都能為有益的微生物提供合適的「居住環境」。

With all these in mind, is it possible to improve our health by altering our microbiota? The short answer is yes, and it can be achieved in two ways. The first is to use FMT to introduce the microbiota to the recipient, as described in the example of how *C. difficile* infection can be treated. Scientists also hope that in the near future, genetically engineered bacteria can act as a tool to be introduced to detect and treat diseases like inflammatory bowel disease, as they can be engineered to produce certain medically beneficial substances [3]. The second option is to change our microbiota composition and metabolism with diet. Dietary patterns can significantly influence our gut microbiota and in turn affect our health. For example, food additives, including sweeteners, have been shown to disrupt gut microbiota balance and diversity, which as mentioned previously, is correlated with metabolic diseases [2]. Meanwhile, high dietary fiber intake was also found to confer short-term health benefits in trials, possibly through the metabolites of the microbiota, like SCFAs [2].

Although the exact mechanisms of how the gut microbiota interacts with the host still need further investigation, it is evident that gut microbiota is crucial to our health. With a better understanding of the interactions with our microbiota, it is possible that the introduction of microbes into guts can become a mainstream treatment of metabolic problems like diabetes and obesity. For now, just reach for the yogurt from the fridge to get some probiotics (beneficial microorganisms) — as we are, literally, living together with the microbes in our guts!



那麼，我們可以通過改變微生物群來改善我們的健康狀況嗎？簡單來說是可以的，而且可以通過兩種方式來實現。第一種方法是使用糞便微生物移植將微生物群引入接受者的體內，如上面關於治療艱難梭菌感染一例所述。科學家們還希望在不久的將來把轉基因細菌引進身體，作為檢測和治療疾病（例如炎症性腸病等）的工具，因為它們可以被改造至能生產一些醫學上有用的物質 [3]。第二個選擇是通過飲食改變我們體內微生物群的組成和代謝。飲食習慣能影響我們的腸道菌群，進而影響我們的健康。例如包括甜味劑在內的一些食品添加劑已被證實能破壞腸道菌群的平衡和多樣性，如前文所述，這與代謝疾病有關 [2]。同時，攝取大量膳食纖維亦被發現能對短期健康帶來好處，這可能是與微生物群的代謝產物相關，如 SCFAs [2]。

雖然腸道菌群與宿主之間相互作用的確切機制仍有待進一步調查，但顯然地腸道菌群對我們的健康非常重要。當科學家進一步了解我們與體內微生物群的相互作用時，將微生物引入腸道就可能會成為治療糖尿病和肥胖症等代謝疾病的主流方法。但現在，我們至少可以從冰箱的乳酪得到一些益生菌來改善健康 — 而我們確實與腸道中的微生物住在一起！

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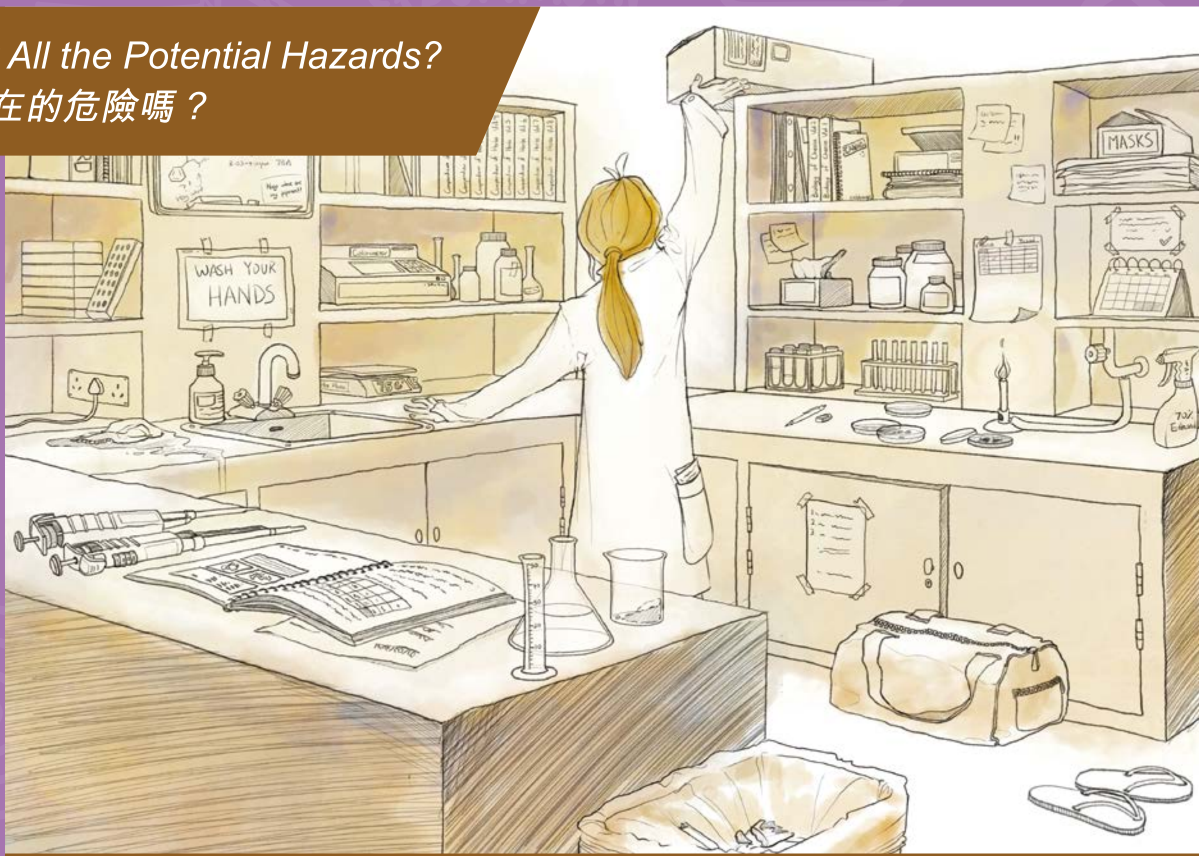
# Lab Safety
# 實驗室安全

By Lynn Zhang 張海琳

*Can You Identify All the Potential Hazards?*
*你能找出所有潛在的危險嗎？*




**Answer key**
**答案**

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